Na temelju knjige:

“Network simulation experiments manual”

Prepared by Emad Aboelela, Ph.D.

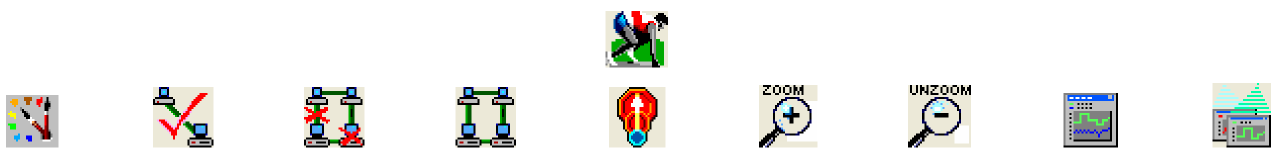
University of Massachusetts Dartmouth

Tonko Kovačević, Marijo Nižetić

PROTOKOLI PAKETSKIH MREŽA

Laboratorijske vježbe

(MATERIJAL U PRIPREMI)



Split: 2010.

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2.5	Token Ring Model Description		
3.5	Building Network Topologies		
4.5	Configuring Applications and Profiles		
5.5	ATM Model Description		
6.5	Routing Information Protocol (RIP)	~~IETF RFC number 2453~~	~~(www.ietf.org/rfc.html)~~
6.5	Internet Control Message Protocol	~~ICMP. IETF RFC number 792~~	~~(www.ietf.org/rfc.html)~~
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15.5	ANSI/IEEE Standard 802.11, 1999 Edition.PDF ANSI_IEEE Standard 802.11_1999 Edition.DOC	~~Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.~~	
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Content

NETWORK SIMULATION EXPERIMENTS MANUAL

Prepared by Professor Hmad Aboelela, University of Massachusetts/Dartmouth

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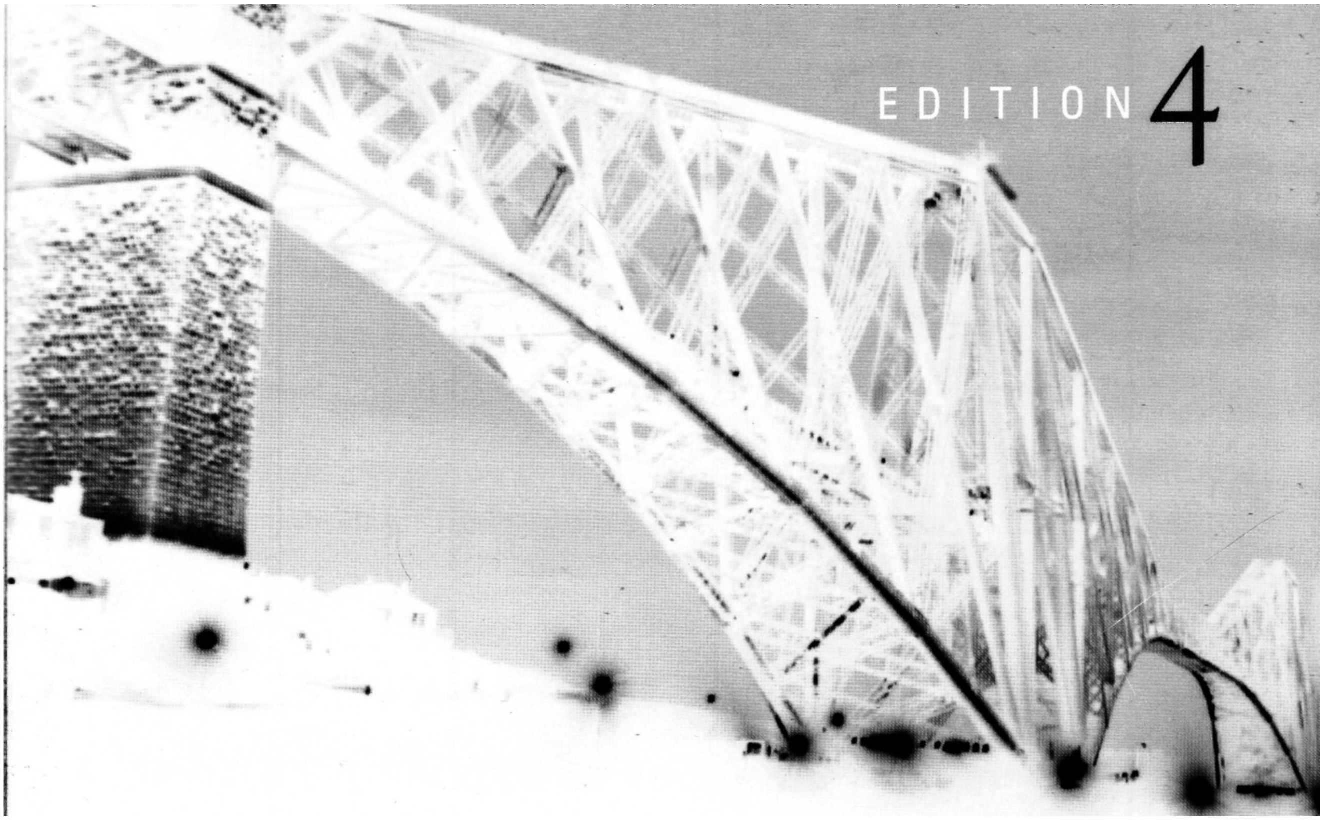

A ⇒ SYSTEMS ⇒ APPROACH

LARRY L. PETERSON AND BRUCE S. DAVIE

NETWORK SIMULATION

EXPERIMENTS MANUAL

Prepared by Emad Aboelela, Ph.D.

University of Massachusetts Dartmouth

NETWORK SIMULATION EXPERIMENTS MANUAL

Second Edition

ELSEVIER

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Contents

area networks connected by *switches* and *hubs*.

In this lab you will set up switched LANs using two different *switching devices*: *hubs* and *switches*. A hub forwards the packet that arrives on any of its inputs on all the outputs regardless of the destination of the packet. On the other hand, a switch forwards incoming packets to one or more outputs depending on the destination(s) of the packets. You will study how the *throughput* and *collision* of packets in a switched network are affected by the *configuration of the network* and the *types of switching devices* that are used.

3.3. Prelab Activities

- Read section 3.1 from ***"Computer Networks: A Systems Approach",*** 4th ***Edition.***

Go to ***www.net-seal.net/animations.php*** and play the following animations:

- Hub.
- Switch.
- Switched Network With No Server.
- Switched Network With Server.

4.1. Objective

The objective of this lab is to demonstrate the basics of **designing a network**, taking into consideration the *users*, *services*, and *locations of the hosts*.

In this lab you will design a network for a company that has four departments: Research, Engineering, E-Commerce, and Sales. You will utilize a LAN model that allows you to simulate multiple clients and servers in one simulation object. This model dramatically reduces both the amount of configuration work you need to perform and the amount of memory needed to execute the simulation. You will be able to define a profile that specifies the pattern of applications employed by the users of each department in the company. By the end of this lab, you will be able to study how different design decisions can affect the performance of the network.

4.3. Prelab Activities

- Read section 3.2 from ***"Computer Networks: A Systems Approach",*** 4th ***Edition.***

Go to ***www.net-seal.net/animations.php*** and play the following animations:

- Adding Switches.

5.1. Objective

The objective of this lab is to examine the effect of **ATM** adaptation layers and service classes on the performance of the network.

In this lab you will set up an *ATM network* that carries three applications: *Voice*, *Email*, and *FTP*. You will study how the choice of the adaptation layer as well as the service classes can affect the performance of the applications.

5.3. Prelab Activities

- Read section 3.3 from ***"Computer Networks: A Systems Approach",*** 4th ***Edition.***

6. Laboratory - RIP: *Routing Information Protocol* (A Routing Protocol Based on the Distance-Vector Algorithm) 65

6.1. Objective

The objective of this lab is to configure and analyze the performance of the **Routing Information Protocol** (RIP) model.

In this lab you will set up a network that utilizes RIP as its *routing protocol*. You will analyze the *routing tables* generated in the *routers*, and you will observe how RIP is affected by *link failures*. You will also utilize the ICMP (Internet Control Message Protocol) to create *echo reply messages* (i.e., *ping*) to analyze the created routes.

6.3. Prelab Activities

- Read sections 4.1.5, 4.1.7, and 4.2.2 from *"Computer Networks: A Systems Approach"*, 4th *Edition.*

Go to www.net-seal.net/animations.php and play the following animations:

- The Address Resolution Protocol (ARP). Example1, Example2, Example3.
- ARP with Multiple Networks.
- Routing and Forwarding.

7. Laboratory - OSPF: *Open Shortest Path First* (A Routing Protocol Based on the Link-State Algorithm) 76

7.1. Objective

The objective of this lab is to configure and analyze the performance of the **Open Shortest Path First** (OSPF) routing protocol.

In this lab, you will set up a network that utilizes OSPF as its *routing protocol*. You will analyze the *routing tables* generated in the routers and will observe how the resulting routes are affected by assigning areas and enabling load balancing.

7.3. Prelab Activities

- Read sections 4.2.3 and 4.2.4 from *"Computer Networks: A Systems Approach"*. 4th *Edition.*

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

- Routing and forwarding.

8. Laboratory - BGP: *Border Gateway Protocol* (An Interdomain Routing Protocol) 86

8.1. Objective

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

In this lab you will set up a network with *three different ASs* (Autonomous Systems). RIP will be used as the intradomain routing protocol and BGP as the interdomain one. You will analyze the *routing tables* generated in the *routers* as well as the effect of applying a simple policy.

8.3. Prelab Activities

- Read section 4.3 from *"Computer Networks: A Systems Approach"*, 4th *Edition.*

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

- IP Subnets.

9. Laboratory - TCP: *Transmission Control Protocol* (A Reliable, Connection-Oriented, Byte-Stream Service) 98

9.1. 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.

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.

9.3. Prelab Activities

- Read sections 5.1 and 5.2 from *"Computer Networks: A Systems Approach"*, 4th *Edition*.

Go to *www.net-seal.net/animations.php* and play the following animations:

- TCP Connections.
- TCP Multiplexing.
- TCP Buffering and Sequencing.
- User Datagram Protocol (UDP).

10. Laboratory - *Queuing Disciplines* (Order of Packet Transmission and Dropping) 109

10.1. Objective

The objective of this lab is to examine the effect of different **queuing disciplines** on ***packet delivery*** and ***delay*** for ***different services***.

In this lab you will set up a network that carries three applications: *FTP*, *Video*, and *VoIP*. You will study how the choice of the *queuing discipline* in the routers can affect the performance of the applications and the utilization of the network resources.

10.3. Prelab Activities

- Read section 6.2 from *"Computer Networks: A Systems Approach"*, 4th *Edition.*

Go to *www.net-seal.net/animations.php* and play the following animations:

- Switch Congestion.
- IP Fragmentation.

11. Laboratory - RSVP: *Resource Reservation Protocol* (Providing QoS by Reserving Resources in the Network) 121

11.1. Objective

The objective of this lab is to study the **Resource Reservation Protocol** (RSVP) as a part of the ***Integrated Services approach*** to providing ***Quality of Service*** (QoS) to individual applications or flows.

In this tab you will set up a network that carries *real-time applications* and that utilizes RSVP to provide QoS to one of these applications. You will study how RSVP contributes to the performance of the application that makes use of it.

11.3. Prelab Activities

Read section 6.5 from *"Computer Networks: A Systems Approach"*, 4th *Edition.*

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

- TCP Flow Control.

12. Laboratory - *Firewalls* and *Virtual Private Networks* (VPN and Network Security) 137

12.1. Objective

The objective of this lab is to study the role of **firewalls** and Virtual Private Networks VPNs) in providing **security** to shared public networks such as the Internet.

In this lab you will set up a network where servers are accessed over the Internet by customers who have different privileges. You will study how firewalls and VPNs can provide *security* to the information in the servers while maintaining access for customers with the appropriate privilege.

12.3. Prelab Activities

- Read section 4.5.3 from *"Computer Networks: A Systems Approach"*, 4th *Edition.*
  - Firewalls

13. Laboratory - *Applications* (Network Application Performance Analysis) 147

13.1. Objective

The objective of this lab is to analyze the performance of an Internet application protocol and its relation to the underlying network protocols. In addition, this lab reviews some of the topics covered in previous labs.

In this lab you will analyze the performance of an FTP application. You will analyze the *probable bottlenecks* for the application scenario under investigation. You will also study the sensitivity of the application to different network conditions such as *bandwidth* and *packet loss*. The trace was captured on a real network, which is shown in the figure below, and already imported into ACE. The FTP application runs on that network; the client connects to the server over a 768 Kbps Frame Relay circuit with 36 ms of latency. The FTP application downloads a 1 MB file in 37 seconds. Normally the download time for a file this size should be about 11 seconds.

13.3. Prelab Activities

- Read sections 9.1.1 and 9.1.3 from *"Computer Networks: A Systems Approach"* 4th *Edition*.

  Go to *www.net-seal.net/animations.php* and play the following animations:
  - Internet Access.
  - Email Protocols

14. Laboratory - *Wireless Local Area* Network (Medium Access Control for Wirelessly Connected Stations) 161

14.1. Objective

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

14.3. Prelab Activities

- Read section 2.8.2 from "Computer Networks: A Systems Approach", 4th Edition.

15. Laboratory - *Mobile Wireless Network* (A Wireless Local Area Network with Mobile Stations) 173

15.1. Objective

This lab simulates mobility in **wireless local area network**. The effect of mobility on the TCP performance is studied. In addition, the lab studies how the request to send (RTS) and clear to send (CTS) frames are utilized in avoiding the hidden node problem usually induced by mobility in WLAN.

In this lab we will simulate a wireless LAN with *mobile workstations* and *server*. The workstations will run an FTP application to upload files to the server. We will study the *effect of node mobility* on the performance of the TCP connection for the *FTP session*. We will study also the role of the *request to send* (RTS) and *clear to send* (CTS) frames in avoiding the *hidden node problem* usually induced by mobility in wireless LAN.

15.3. Prelab Activities

- Read sections 2.8.2 and 4.2.5 from ***"Computer Networks: A Systems Approach"*** 4th ***Edition.***
  - Wireless Network and Multiple Access with Collision Avoidance

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	2.8.2		4.1.5 4.1.7 4.2.2 4.2.3 4.2.4 4.2.5 4.5.3					9.1.1 9.1.3

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9.1.3

Preface

Welcome to the *Network Simulation Experiments Manual, 2nd Edition*. As networking systems have become more complex and expensive, hands-on experiments based on networking simulation have become essential for teaching the key computer networking topics to students and professionals. The simulation approach is highly useful because it provides a virtual environment for a variety of desirable features such as modeling a network based on specified criteria and analyzing its performance under different scenarios.

This manual has 15 laboratory experiments that cover a variety of networking designs and protocols. The experiments in this manual do not require programming skills as a prerequisite. They are generic and can be easily expanded to utilize new technologies and networking standards. With the free easy-to-install software, the **OPNET IT Guru Academic Edition**, networking students and professionals can implement the experiments from the convenience of their homes or workplaces. The manual is suitable for a single-semester course on computer networking at the undergraduate or beginning graduate level. Professors can pick the experiments that arc appropriate to their class.

The new materials in the 2nd edition of the manual are:

- A new ***Prelab Activities*** section in every laboratory assignment. This section includes recommended readings from the textbook as well as references to animations from the Net-SEAL project (www.net-seal.net)[1]. These activities are intended to reinforce the student's understanding of the concepts related to the topics covered in the laboratory.
- Two new laboratory experiments to cover wireless networking protocols.
- One new laboratory experiment to cover the Border Gateway Protocol (BGP).
- A new component to address the ICMP protocol has been added to the RIP lab.
- A new component to address the effect of encryption has been added to the VPN lab.

OPNET IT Guru Academic Edition provides a virtual environment for modeling, analyzing, and predicting the performance of IT infrastructures, including applications, servers, and networking technologies. Based on OPNET's award-winning IT Guru product, Academic Edition is designed to complement specific lab exercises that teach fundamental networking concepts. The commercial version of IT Guru has broader capabilities designed for the enterprise II environment, documentation, and professional support. OPNET software is used by thousands of commercial and government organizations worldwide, and by over 500 universities. For more information, visit www.opnet.com. OPNET and IT Guru are trademarks of OPNET Technologies, Inc.

I would like to extend my appreciation to Professor Larry Peterson and Dr. Bruce Davie for giving me the opportunity to associate the laboratory experiments of this manual with their valuable book. I want to thank the folks at Morgan Kaufmann who have helped to bring this project to life. Many thank to the reviewers from academia and OPNET, who read through the various drafts of the experiments and provided me with extremely valuable feedback. My gratitude to the Net-SEAL project team, with special appreciation to Neal Charbonneau for the superb job he did in the project. I want to thank my family for their consideration and enthusiastic assurance throughout the development of this project. Last, but not least, I want to thank you for choosing the manual. I welcome your emails to report bug or to suggest improvements.

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University of Massachusetts Dartmouth
July 2007.

[1] The materials in the www.ncl-scal.net website are based upon work supported by the National Science Foundation under Grant No. DUF-0536388. Any opinions, findings and conclusions or recommendations expressed in this website are those of the Net-SEAL project team and do not necessarily reflect the views of the National Science Foundation (NSF).

0. Laboratory - Introduction (Basics of OPNET IT Guru Academic Edition)

0.1. *Objective*

This lab teaches you the basics of using OPNET IT Guru Academic Edition. OPNET IT Guru Academic Edition enables students to better understand the core concepts of networking and equips them to effectively troubleshoot and manage real-world network infrastructures.

0.2. *Overview*

OPNET's IT Guru provides a Virtual Network Environment that models the behavior of your entire network, including its routers, switches, protocols, servers, and individual applications. By working in the Virtual Network Environment, IT managers, network and system planners, and operations, staff are empowered to diagnose difficult problems more effectively, validate changes before they are implemented, and plan for future scenarios including growth and failure.

OPNET's **Application Characterization** Environment (ACE) module for IT Guru enables enterprises to identify the root cause of end-to-end application performance problems and to solve them cost-effectively by understanding the impact of changes.

In this lab, you will learn the basics of the **OPNET IT Guru Academic Edition** software. You will learn how to setup and run **OPNET IT Guru Academic Edition**. You will become familiar with some of its capabilities by running some tutorials.

The labs in this manual are implemented with **OPNET IT Guru Academic Edition** release 9.1.A (Build 1997). If you want to download the software, please visit the following site to register with OPNET technology:

www.opnet.com/university_program/itguru_academic_edition/

http://www.opnet.com/itguru-academic/registration.html

Recommended System Configuration, Platforms, and Software:

- 1.5 GHz processor or better
- 512 MB - 2 GB RAM
- 1 GB disk space
- Display: 1024 x 768 or higher resolution, 256 or more colors
- Adobe Acrobat reader.
- The English language version of the following operating systems are supported:
    - Microsoft Windows NT (Service Pack 3.5, or 6a)
    - Windows 2000 Professional (Service Pack 1, 2, and 4 are supported but not required)

Windows XP (Service Pack 1 is required; Service Pack 2 is supported but not required.)

0.3. *Prelab Activities*

- Read Chapter 1 from *"Computer Networks: A Systems Approach"*, 4th *Edition*.

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

- No Network.

0.4. *Procedure*

0.4.1. Start OPNET IT Guru Academic Edition

To start **OPNET IT Guru Academic Edition**:

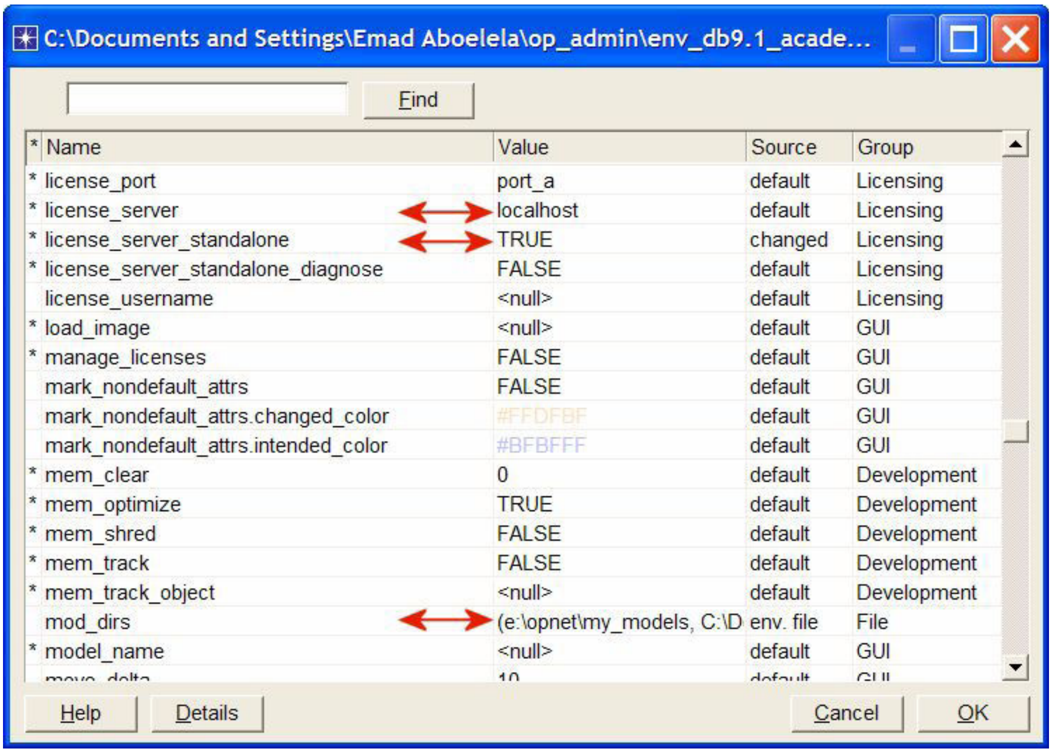
1. Click on Start ⇒ Programs ⇒ **OPNET IT Guru Academic Edition** x.x ⇒ **OPNET IT Guru Academic Edition**, where x.x is the software version (e.g., 9.1)
2. Read the Restricted Use Agreement and if you agree, click I have read this SOFTWARE AGREEMENT and I understand and accept the terms and conditions described herein.

Now you should see the starting window of **OPNET IT Guru Academic Edition** as shown:

0.4.2. Check the OPNET Preferences

The OPNET Preferences let you display and edit environment attributes, which control program operations. In this lab you will check three of these attributes.

1. After starting OPNET, from the **Edit** menu, choose **Preferences.**
2. The list of environment attributes is sorted alphabetically according to name. You can locate attributes faster by typing any part of the attribute's name in the **Find** field.
3. Check the value of the **license_server** attribute. It has the name of the License Server's host. If IT Guru is getting its license from the local host (i.e., the computer on which the software was installed), the value of **license_server** should be **localhost** as shown in the following figure.



4. Set the **license_server_standalone** attribute to TRUE. This attribute specifies whether the program acts as its own license server.

5. A model directory is a directory that contains OPNET model files. If the directory is listed in the **mod_dirs** environment attribute, then OPNET programs will use the models in that directory. Check the value of the **mod_dirs** attribute. The first directory in the list is where your own models will be saved. In the future you might need to access that directory to back up, copy, or move your models. IT Guru saves numerous files for every single project you create.

6. Click **OK** to close the dialog box.

0.4.3. Run the Introduction Tutorial

Now you will run the introductory tutorial that teaches you the basics of using OPNET IT Guru.

1. From the **Help** menu, select **Tutorial**.

2. Go over the Introduction lesson from the list of *Basic Lessons*.

0.4.4. Run the Small Internetworks Tutorial

In this tutorial you will learn how to use OPNET IT Guru features to build and analyze network models.

1. From the **Help** menu, select **Tutorial.**

2. Carry out the Small Internetworks tutorial from the list of *Basic Lessons.*

0.5. *Further readings*

- OPNET Standard Network Applications: From the **Protocols** menu, select **Applications** ⇒ **Model Usage Guide** ⇒ Standard Network Applications.

- From the **Help** menu, select **Tutorial.** ⇒ Carry out the Troubleshooting Tutorial Simulations tutorial from the list of *Basic Lessons.*

0.6. *Exercises*

1) In the project you created for the **Small Internetworks** tutorial, add a new scenario as a duplicate of the **first_floor** scenario. Name the new scenario **expansion2**. In the **expansion2** scenario expand the network the same way as in the **expansion** scenario but with 30 nodes in the second floor instead of 15 nodes. Run the simulation and compare the load and delay graphs of this new scenario with the corresponding graphs of the **first_floor** and **expansion** scenarios.

0.7. *Lab Report*

The laboratory report of this lab (and also all the following labs in this manual) should include the following items/sections:

2) A cover page with your name, course information, lab number and title, and date of submission.
3) A summary of the addressed topic and objectives of the lab.
4) Implementation: a brief description of the process you followed in conducting the implementation of the lab scenarios.
5) Results obtained throughout the lab implementation, the analysis of these results, and a comparison of these results with your expectations.
6) Answers to the given exercises at the end of the lab. If an answer incorporates new graphs, analysis of these graphs should be included here.
7) A conclusion that includes what you learned, difficulties you faced, and any suggested extensions/improvements to the lab.

1. Laboratory - Ethernet (A Direct Link Network with Media Access Control)

1.1. *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.

1.2. *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 thirty 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.

1.3. *Prelab Activities*

- Read section 2.6 from ***"Computer Networks: A Systems Approach"***, 4" Edition.

  Go to ***www.net-seal.net/animations.php*** and play the following animation:
  - Hub.

1.4. *Procedure*

1.4.1. Create a New Project

To create a new project for the Ethernet network:

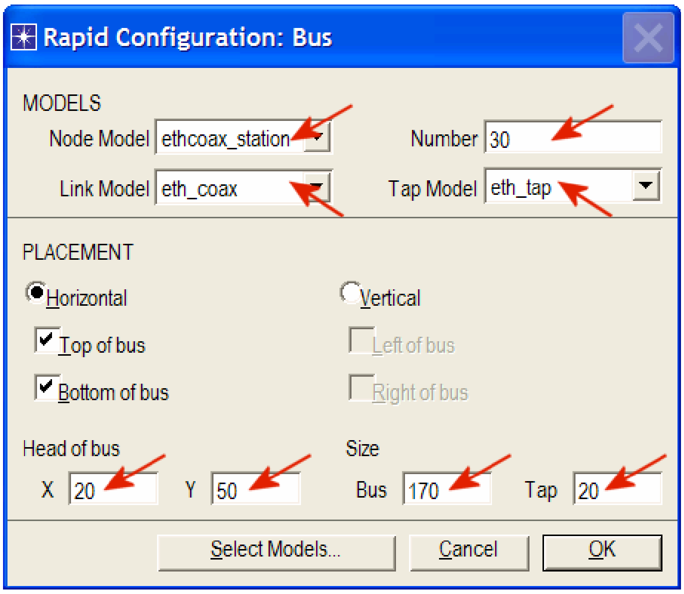
1. Start **OPNET IT Guru Academic Edition** ⇒ Choose **New** from the **File** menu.
2. Select **Project** ⇒ Click **OK** ⇒ Name the project **<your initials>_Ethernet**, and the scenario **Coax** ⇒ Click **OK.**
3. In the *Startup Wizard: Initial Topology* dialog box, make sure that **Create Empty Scenario** 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.

1.4.2. Create the Network

To create our coaxial Ethernet network:

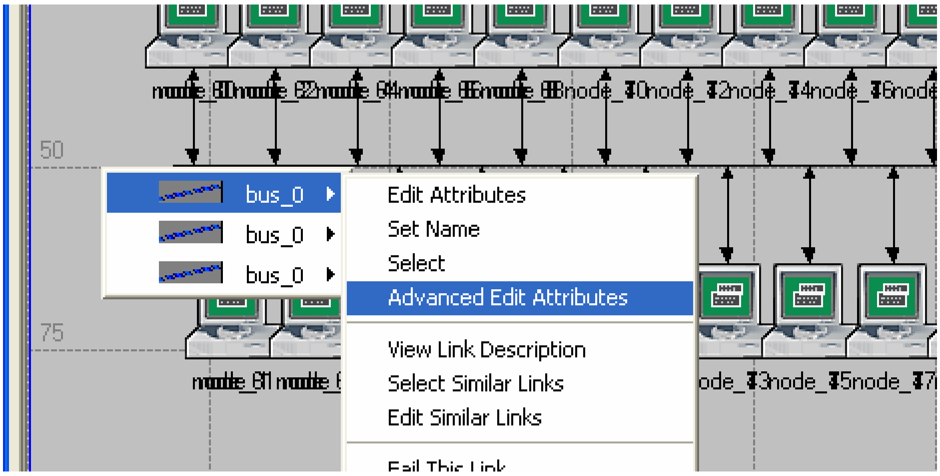
1. To create the network configuration, select **Topology** ⇒ **Rapid Configuration**. From the drop-down menu choose **Bus** and Click **OK.**
2. Click the **Select Models** button in the *Rapid Configuration* dialog box. From the *Model List* drop-down menu choose **ethcoax** and Click **OK.**
3. In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



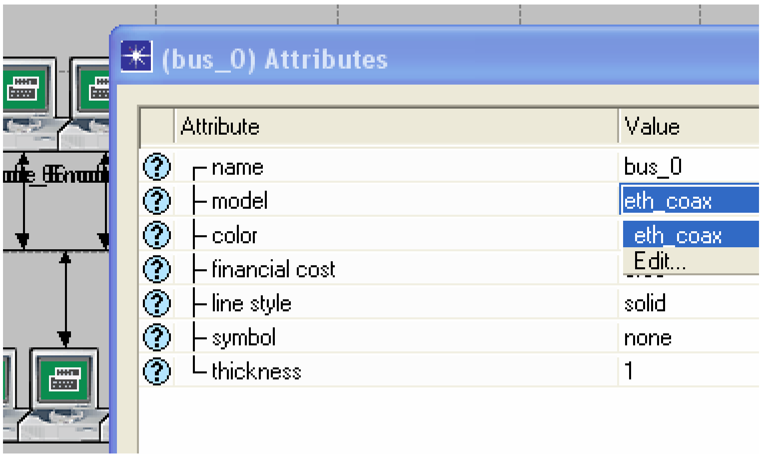
4. Click **OK.**

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

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



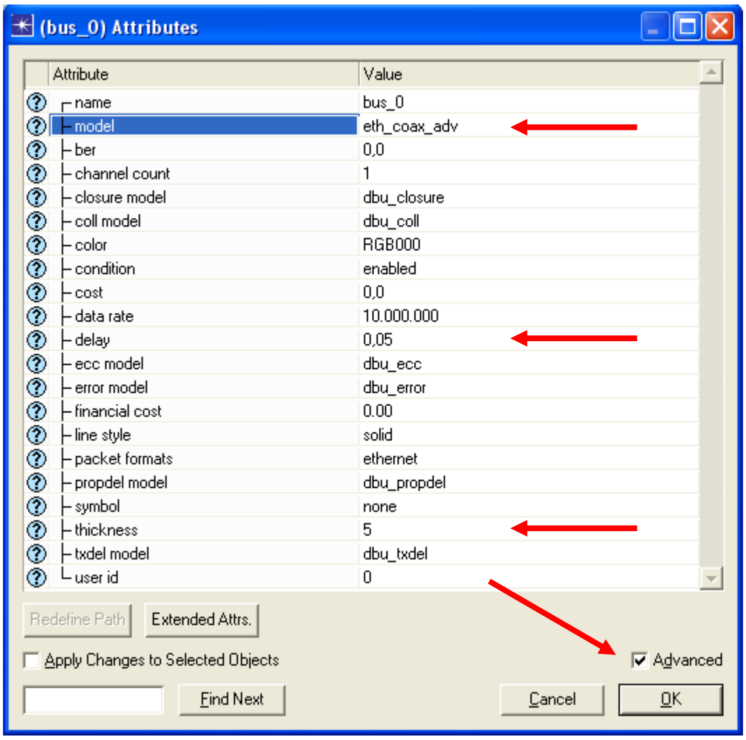
5. To configure the coaxial bus, right-click on the horizontal link ⇒ Select **Advanced Edit Attributes** from the menu:



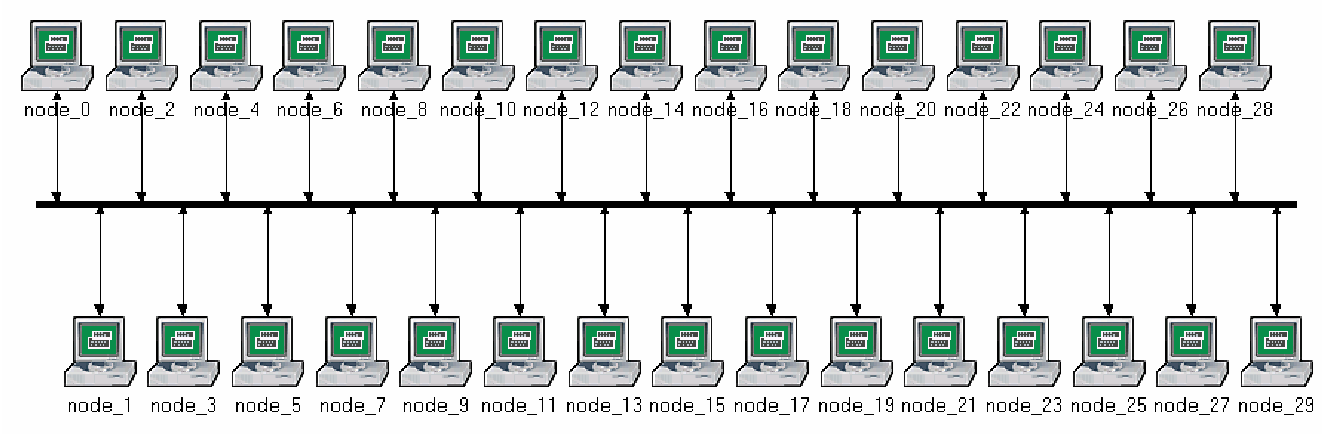
a. Click on the **value** of the **model** attribute ⇒ Select **Edit** from the drop-down menu ⇒ Choose the **eth_coax_adv** model.
b. Assign the value **0.05** to the **delay** attribute (propagation delay in sec/m).
c. Assign **5** to the **thickness** attribute.
d. Click **OK.**

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.



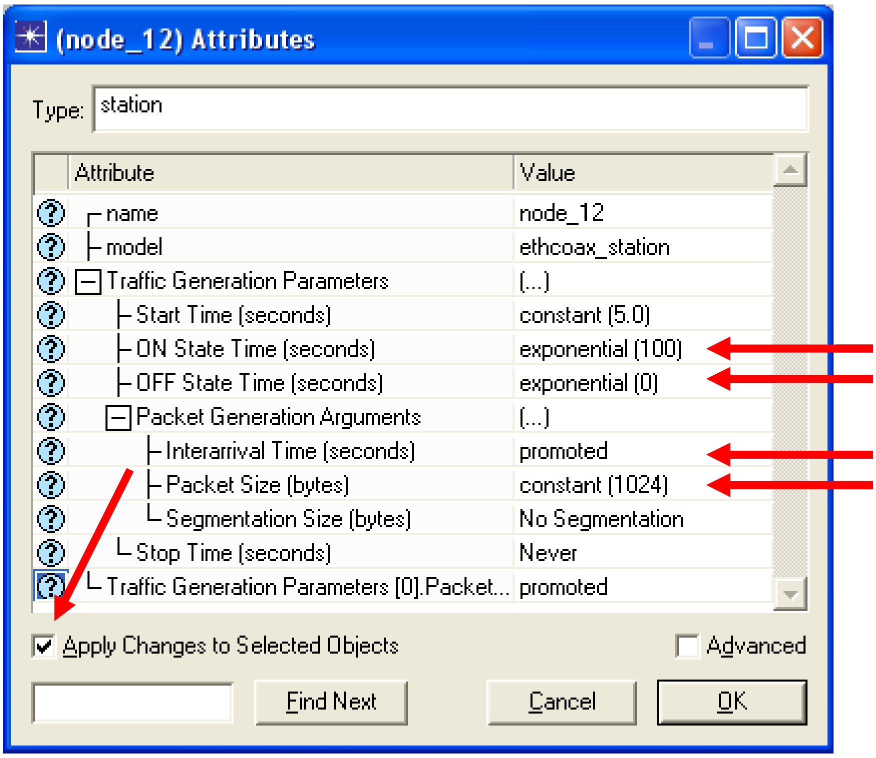
6. Now you have created the network. It should look like the illustration below.
7. Make sure to save your project.



1.4.3. 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 <u>important to avoid reconfiguring each node individually</u>.
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*: <u>Packets are generated only in the ON state</u>.)
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.



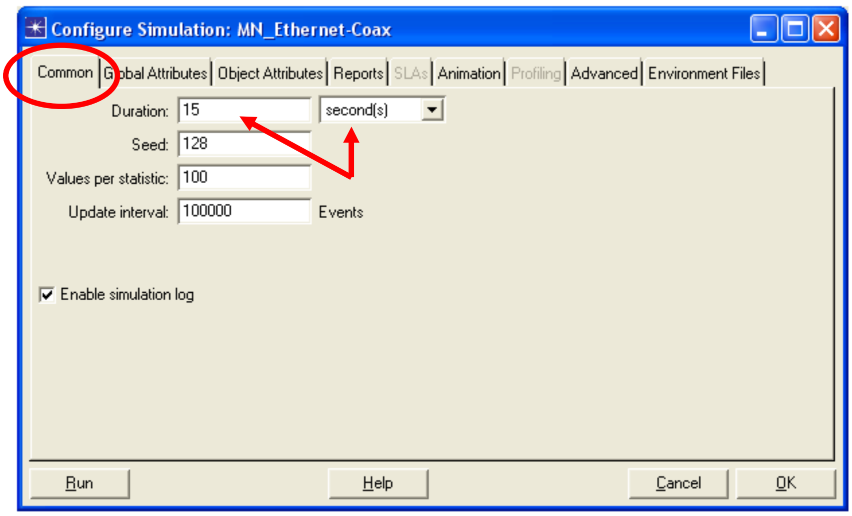
6. Click **OK** to return back to the *Project Editor*.
7. Make sure to save your project.

> 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 name is not at all dependent upon the time of occurrence of the last event of the elapsed time since that event.
>
> The **interarrival time** is the time between successive packet generations in the "ON" state.

1.4.4. 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:

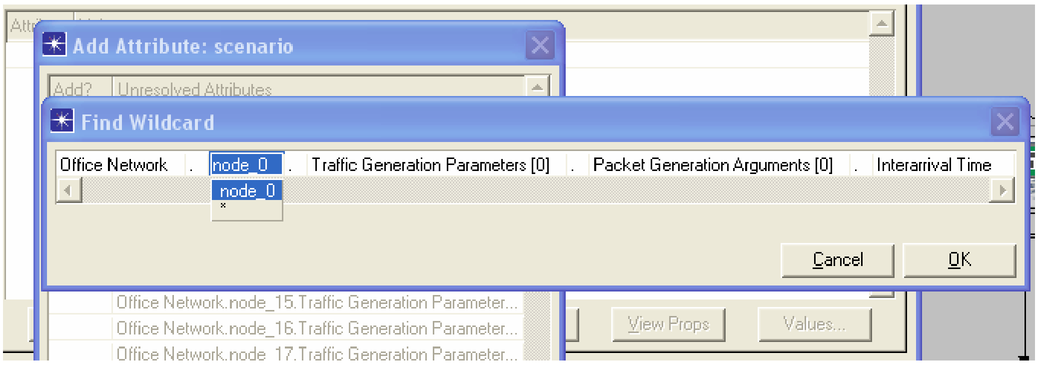
1. Click on the **Configure/Run Simulation** button:  ⇒ Make sure that the **Common** tab is chosen ⇒ Assign **15** seconds to the **Duration**.



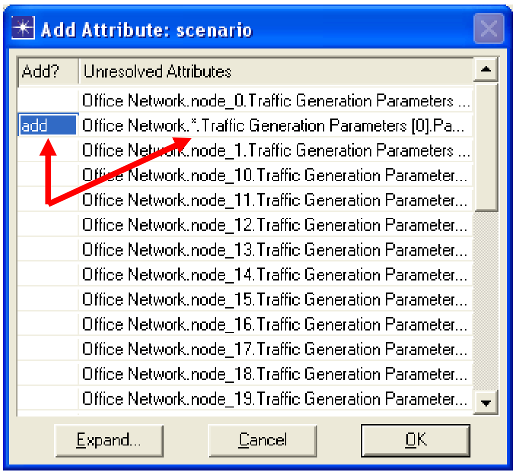
2. Click on the **Object Attributes** tab.

3. 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.**



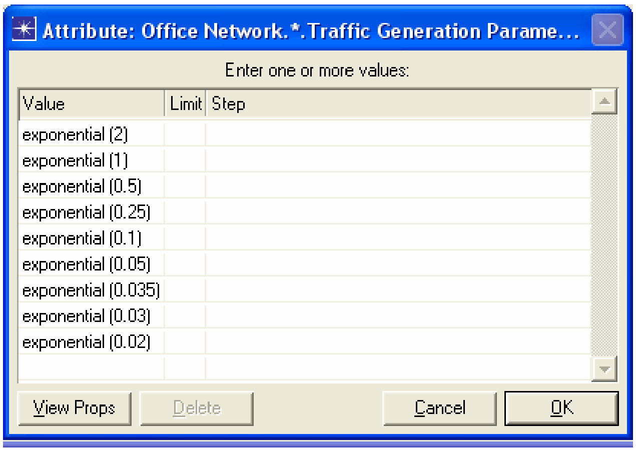
   b. A new attribute is now generated containing the asterisk (the second one in the list), and you need to add it by clicking on the corresponding cell under the **Add?** column.



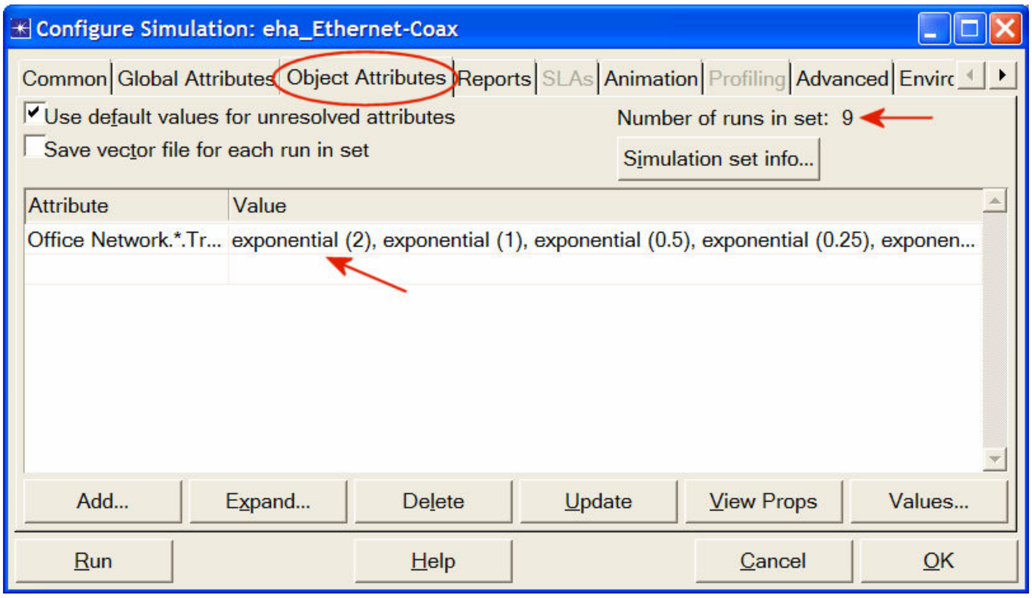
   c. The *Add Attribute* dialog box should look like the shown one ⇒ Click **OK**.

4. 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.

5. 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.)

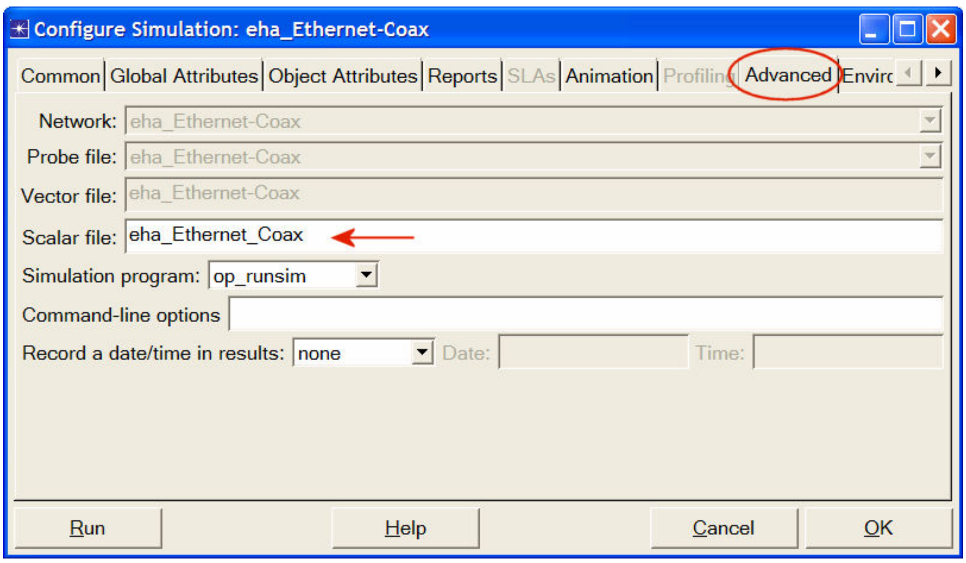


6. Click **OK**. Now look at the upper-right comer of the *Simulation Configuration* dialog box and make sure that the *Number of runs in set* is 9.



7. 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.

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

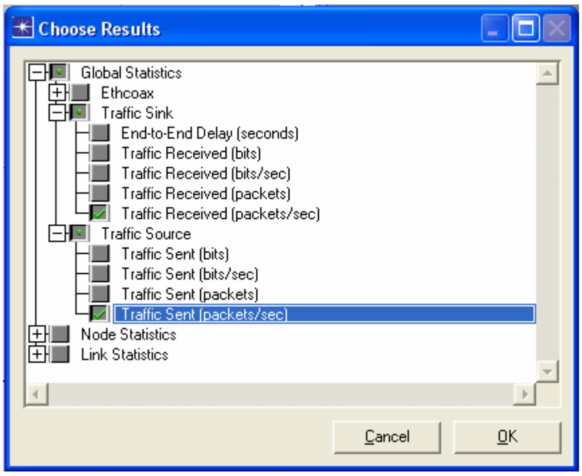


9. Click **OK** and then save your project.

1.4.5. Choose the Statistics

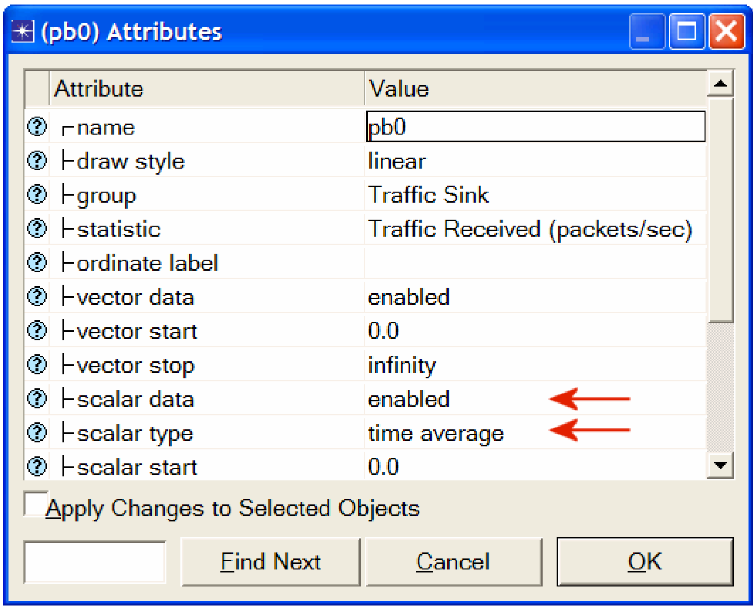
To choose the statistics to be collected during the simulation:

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.



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

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.

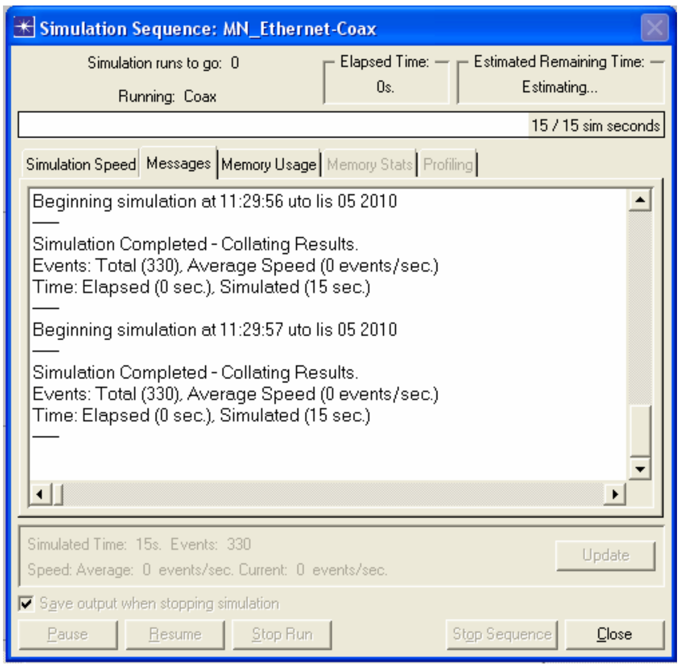
e. Select **save** from the **File** menu in the *Probe Model* window and then close that window.

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

1.4.6. Run the Simulation

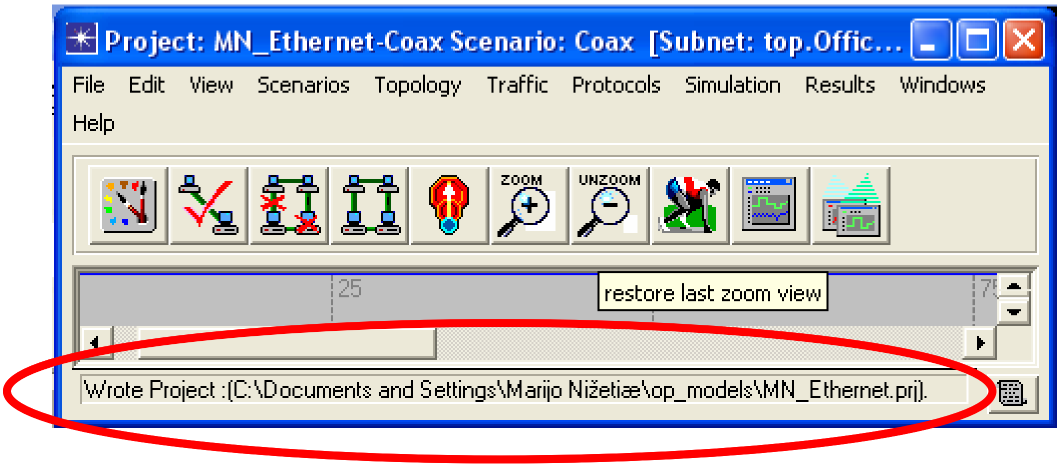
To run the simulation:

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 inter-arrival 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.



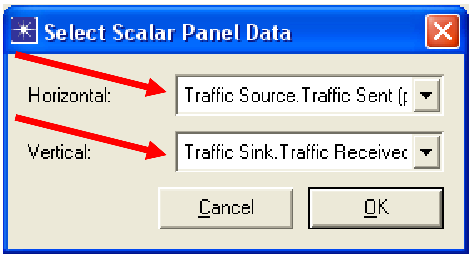
When you rerun the simulation, OPNET IT Guru will "append" the new results to the results already in the scalar file. To avoid that, delete the scalar file *before* you start a new run. (*Note:* Deleting the scalar file after a run will result in losing the collected results from that run.)

- 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** ⇒ Confirm the deletion by clicking **OK** ⇒ Click **Close.**

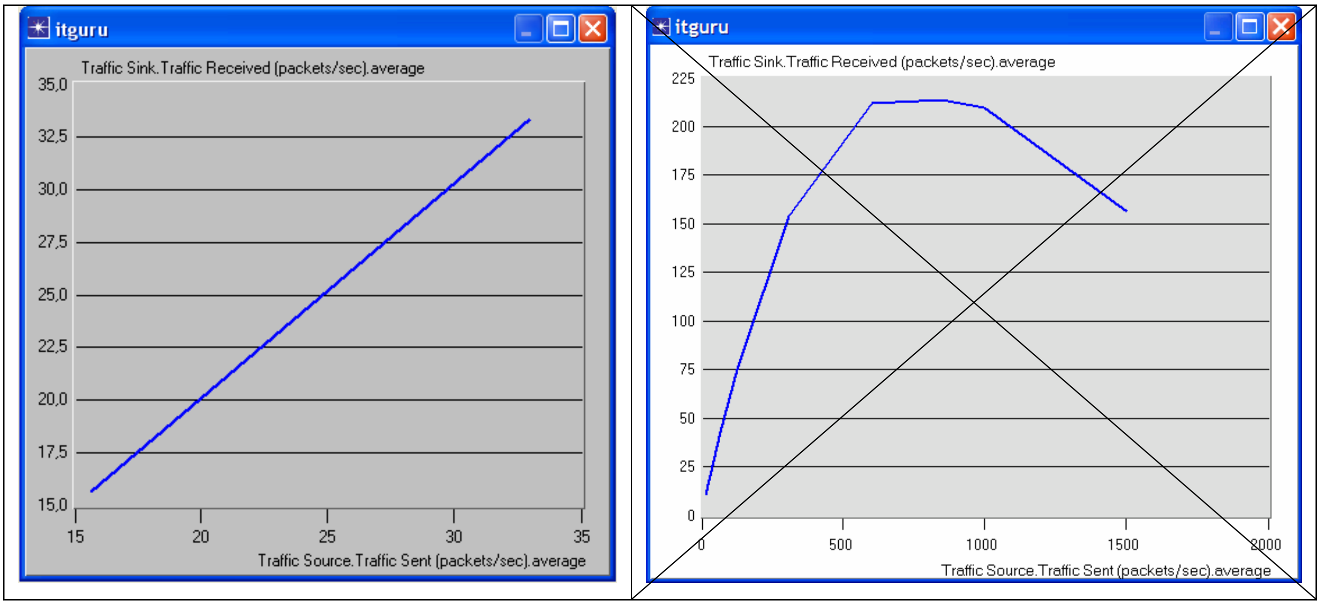
1.4.7. View the Results

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:



Note: Check ordinate scale!

1.5. *Further readings*

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

1.6. *Exercises*

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 tab. 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)**

3) 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).

4) 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.)

5) 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.)

6) 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 Exercise 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.

7) 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 Exercise 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.

1.7. *Lab Report*

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

2. Laboratory - Token Ring (A Shared-Media Network with Media Access Control)

2.1. *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.

2.2. *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. The destination node, which is identified in the frame header, saves a copy of the frame as the frame flows past the node. 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 multi-station 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 ***token holding time*** THT.

2.3. *Prelab Activities*

- Read section 2.7 from ***"Computer Networks: A Systems Approach",*** 4th ***Edition.***

2.4. *Procedure*

2.4.1. Create a New Project

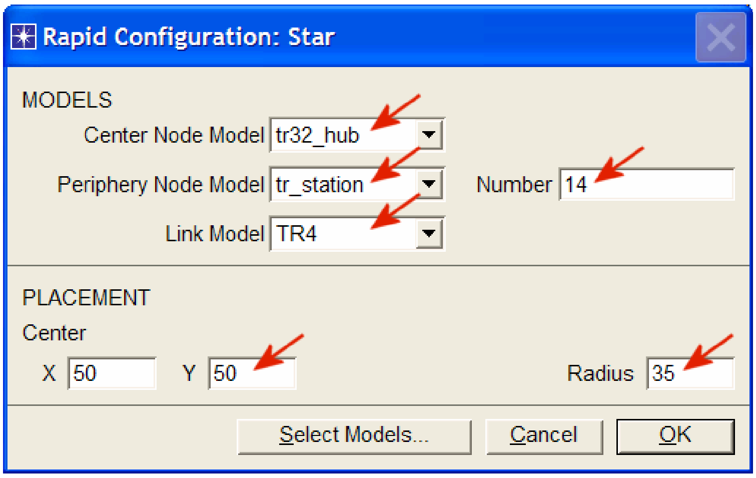
To create a new project for the token ring network:

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.

2.4.2. Create the Network

To create our token ring network:

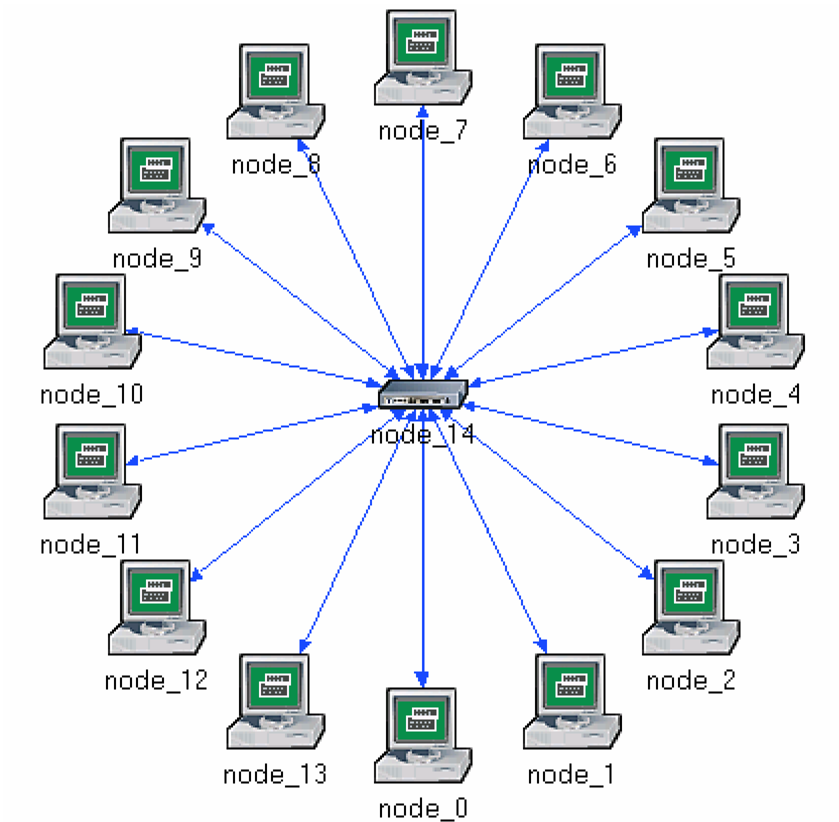
1. Select **Topology** ⇒ **Rapid Configuration**. From the drop-down menu choose **Star** and Click **OK.**
2. Click the **Select Models** button in the *Rapid Configuration* dialog box. From the *Model List* drop-down menu choose **token_ring** and Click **OK.**
3. In the *Rapid Configuration* dialog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



The **tr.32_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:



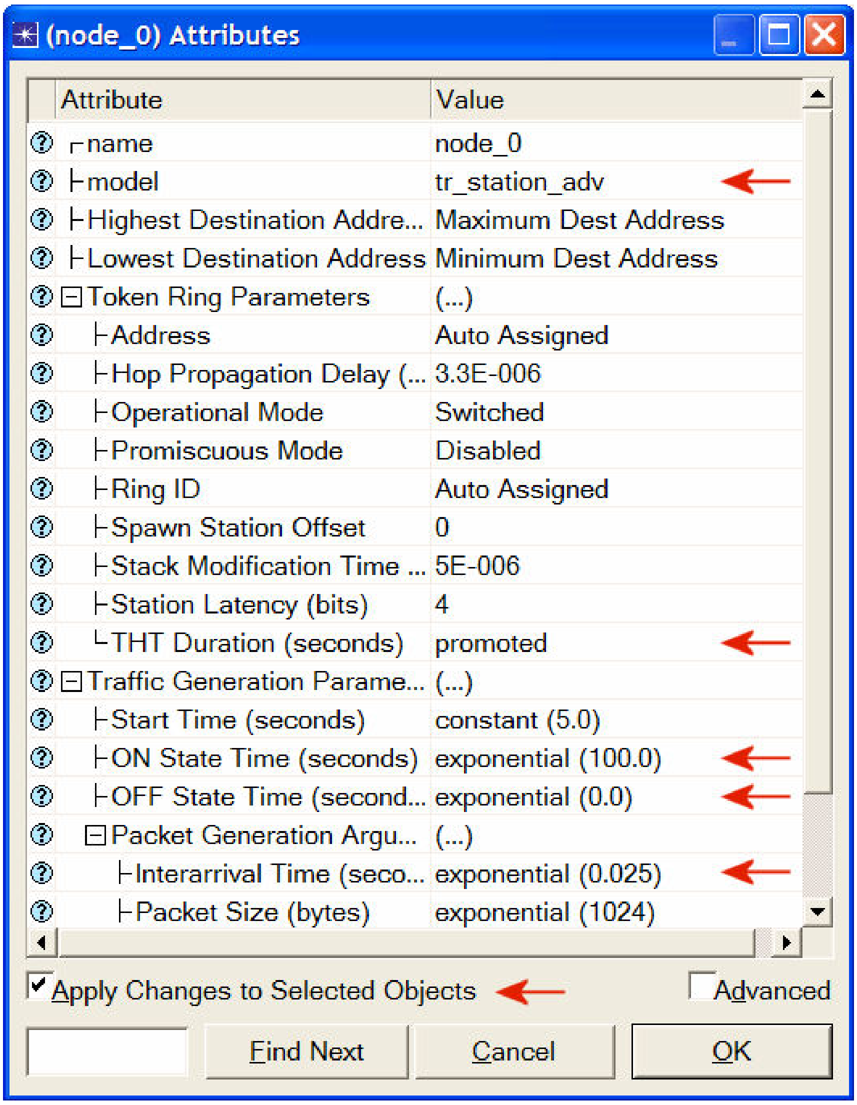
5. Make sure to save your project.

2.4.3. 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.

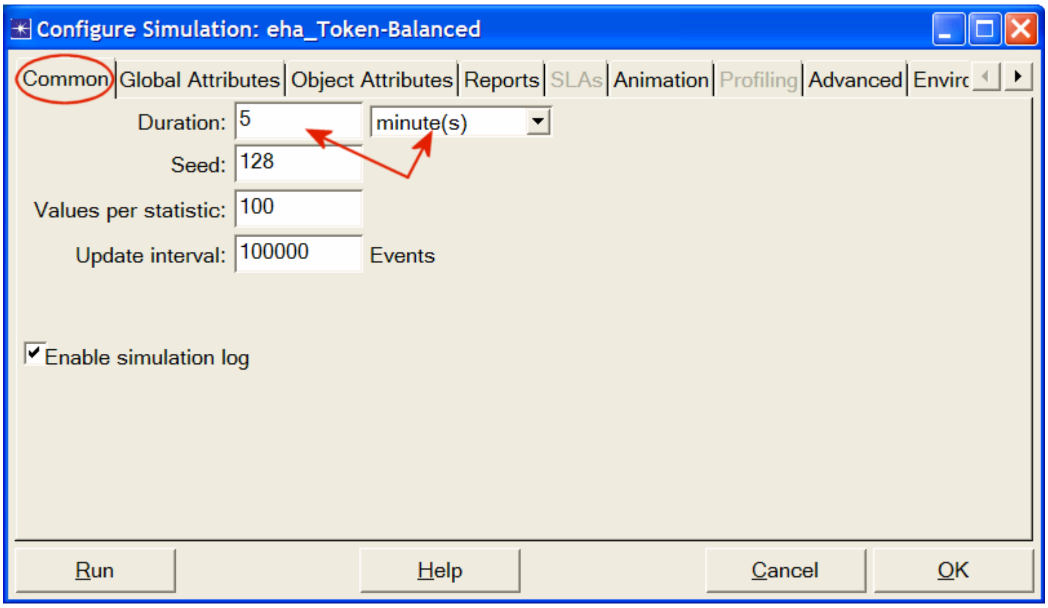
b. Right-click on the **THT Duration** attribute. ⇒ Choose **Promote Attribute to Higher Level**.

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.

2.4.4. Configure the Simulation

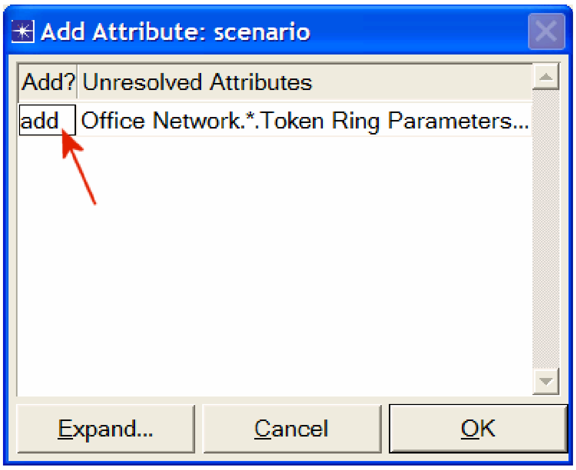
To examine the network performance under different THTs, you need to run the simulation several times by changing **THT** with every run of the simulation. There is an easy way to do that. Recall that we promoted the **THT Duration** attribute. Here we will assign different values to that attribute:

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

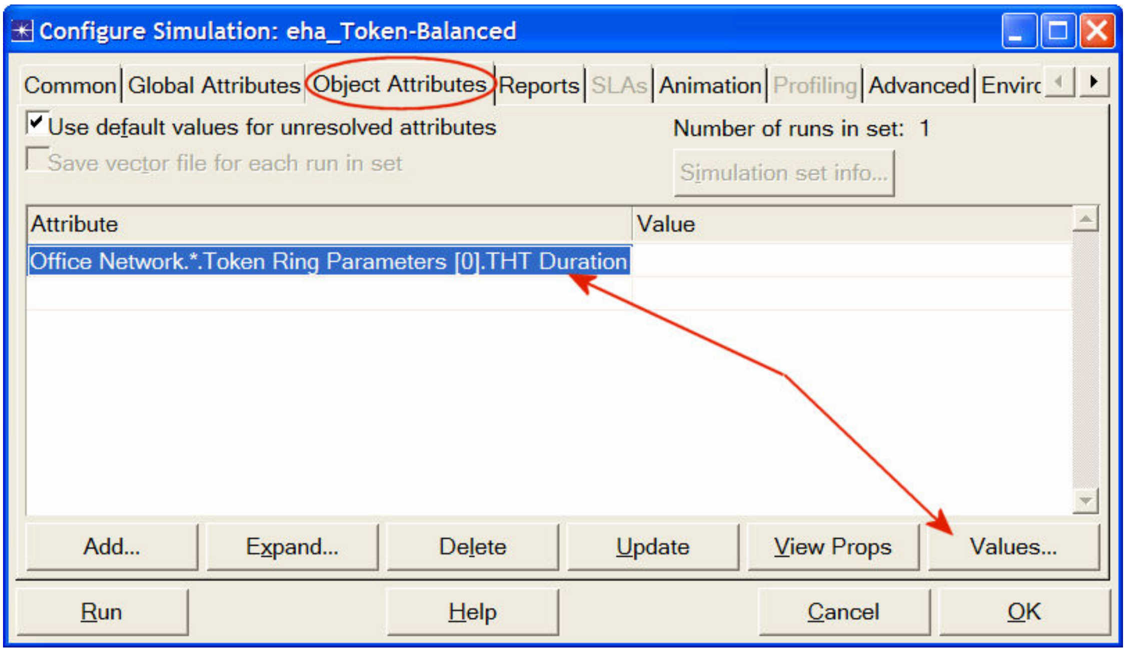


3. Click on the **Object Attributes** tab. ⇒ Click the **Add** button.
4. As shown in the following *Add Attribute* dialog box, you need to add the **THT Duration** attribute for all nodes. To do that:

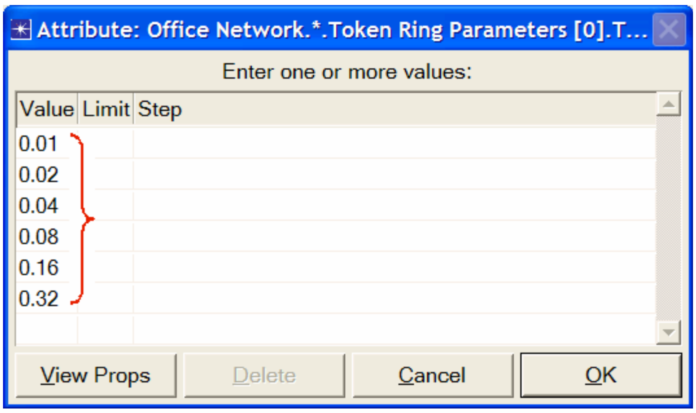
   a. Add the unresolved attribute: **Office Network.*.Token Ring Parameters[0].THT Duration** by clicking on the corresponding cell under the **Add?** column ⇒ Click **OK.**



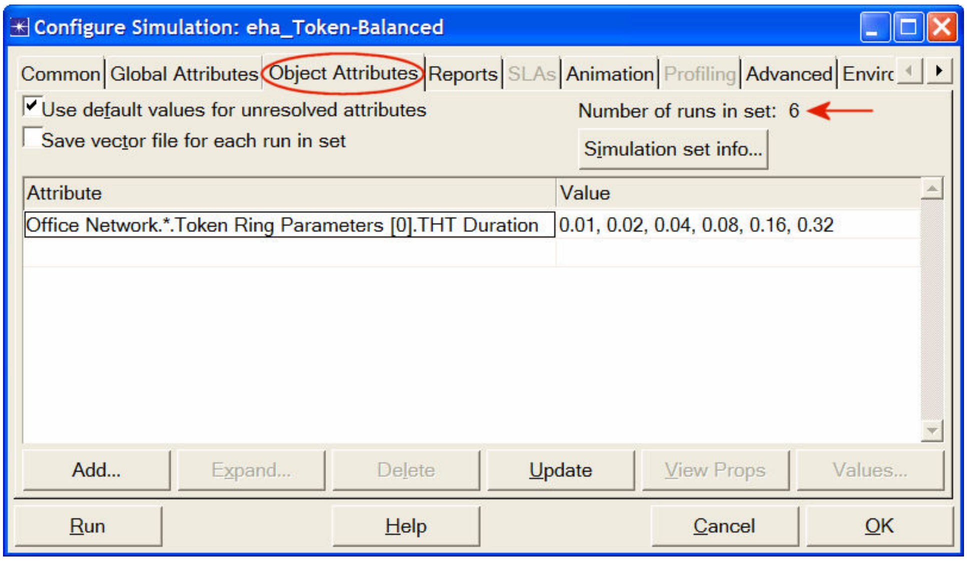
5. Now you should see the **Office Network.*.Token Ring Parameters[0].THT. Duration** in the list of simulation object attributes (widen the "Attribute" column to see the full name of the attribute). Click on that attribute ⇒ Click the **Values** button, as shown below.



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.)

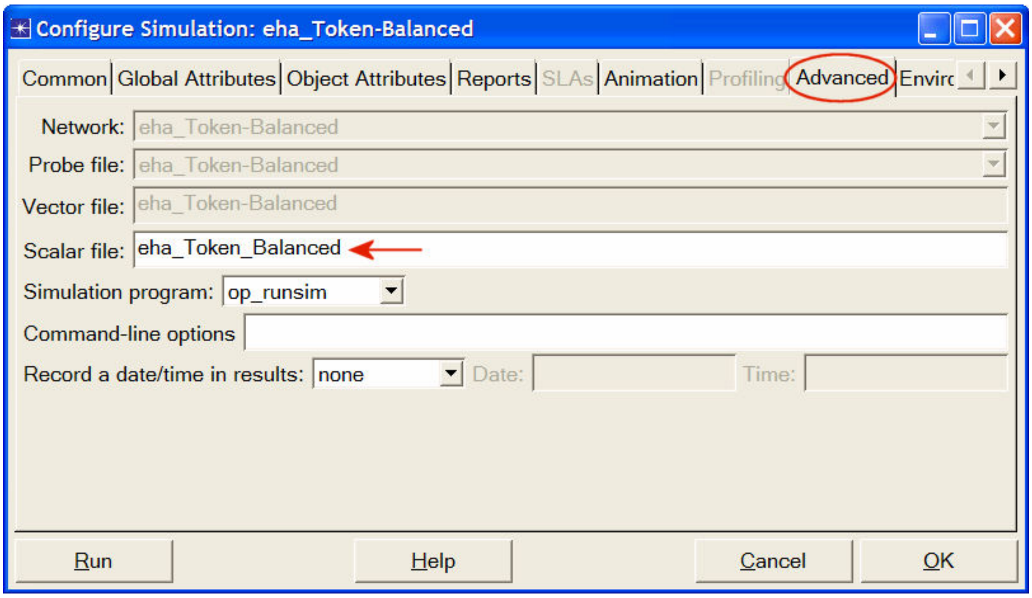


7. Click **OK**. Now look at the upper-right comer of the *Simulation Configuration* dialog box and make sure that the *Number of runs in set* is 6.



8. For each of the six simulation runs we need the simulator to save "scalar" values that represent the "average" values of the collected statistics. 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.

2.4.5. 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).**

   b. Expand the **Node Statistics** hierarchy:

- Expand the **Token Ring** hierarchy. ⇒ Click the check box next to **Utilization.**

c. Click **OK.**

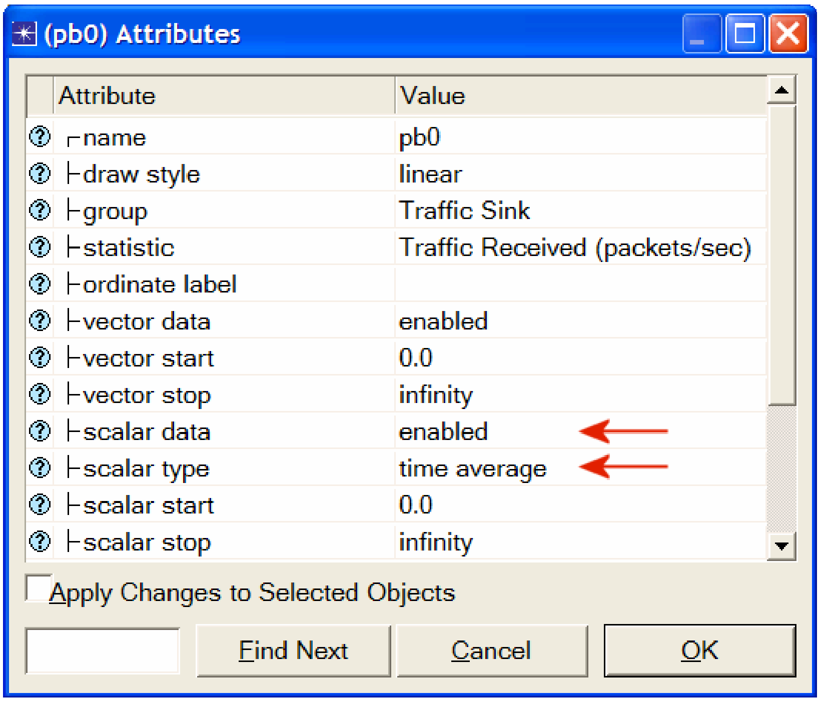
The **utilization** is a measure of the bandwidth used versus that available on the given ring.

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.

   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**.



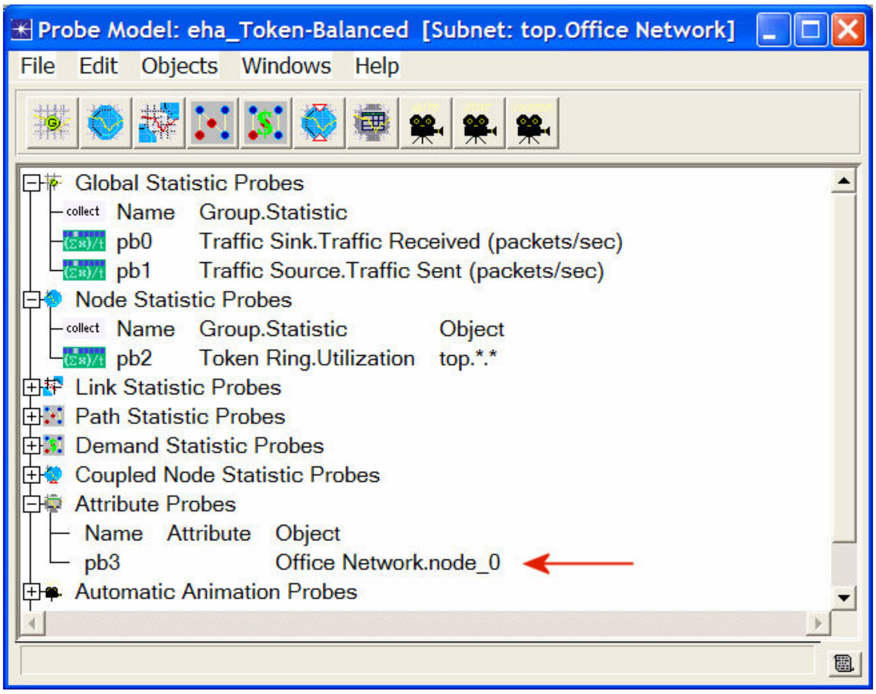
   d. Repeat the previous step with the **Traffic Sent** and **Utilization** probes.

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

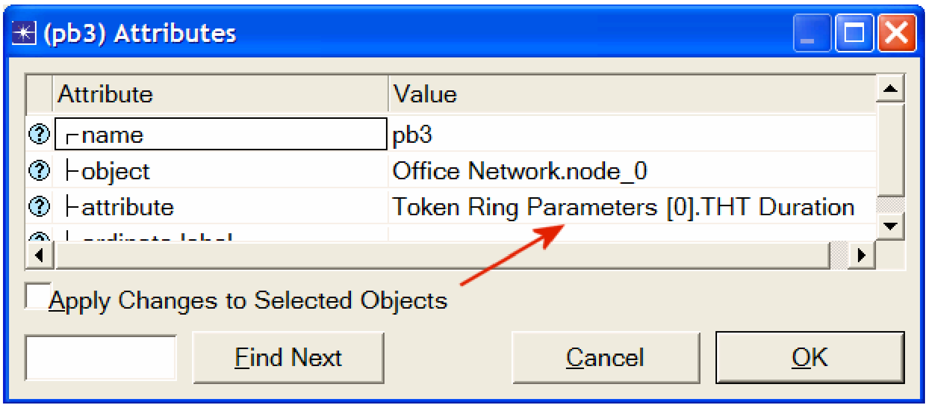
3. Since we need to analyze the effect of THT on the network performance, THT must be added as an "input" statistic to be recorded by the simulation. To do that:

   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.

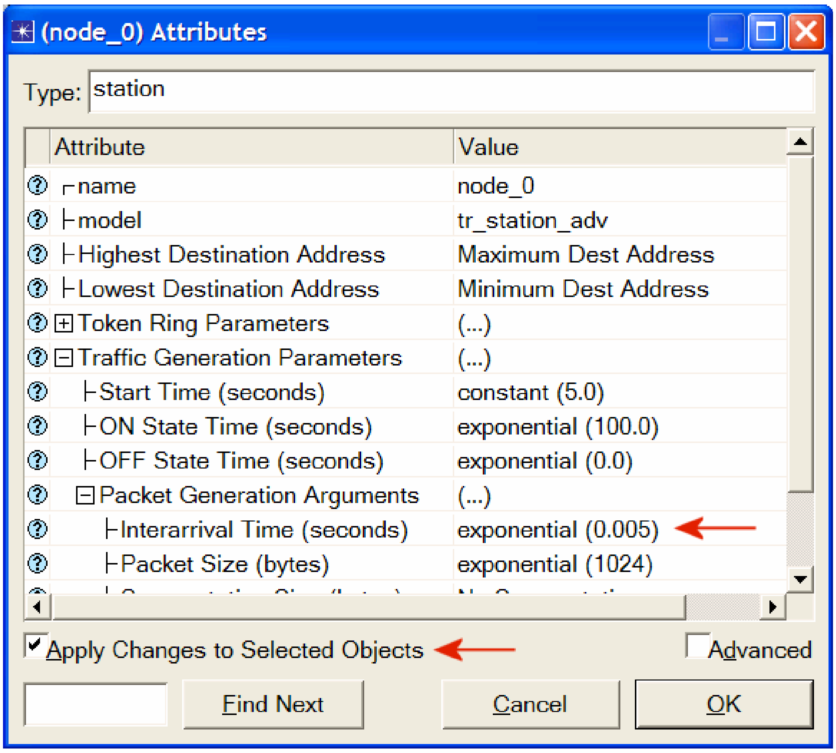
5. Now you are back to the *Project Editor*. Make sure to save your project.

2.4.6. 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**.

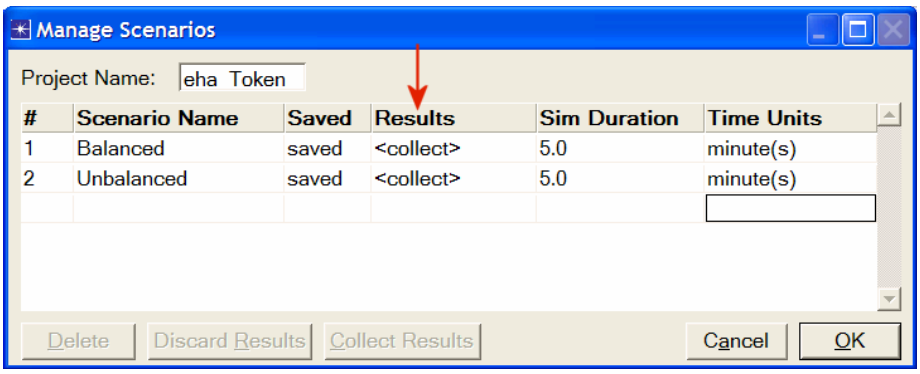


3. Select all nodes **except node_0** and **node_7** ⇒ Right-click on one of the selected nodes and select **Edit Attributes.** ⇒ Change the value of the **Interarrival Time** attribute to **exponential(0.075)** as in the previous step. Make sure to check the **Apply Changes to Selected Objects** box 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.

2.4.7. 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.

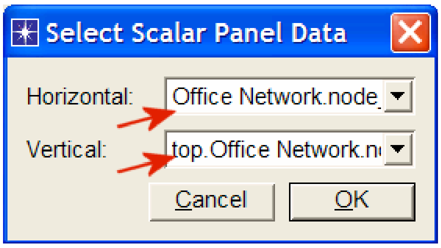
When you rerun the simulation, OPNET IT Guru will "**append**" the new results to the results already in the scalar file. To avoid that, delete the scalar file before you start a new run.

- 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 tab they are:
    - **<your initials>_Token_Balanced** and
    - **<your initials>_Token_Unbalanced**. ⇒ Click **Close**.

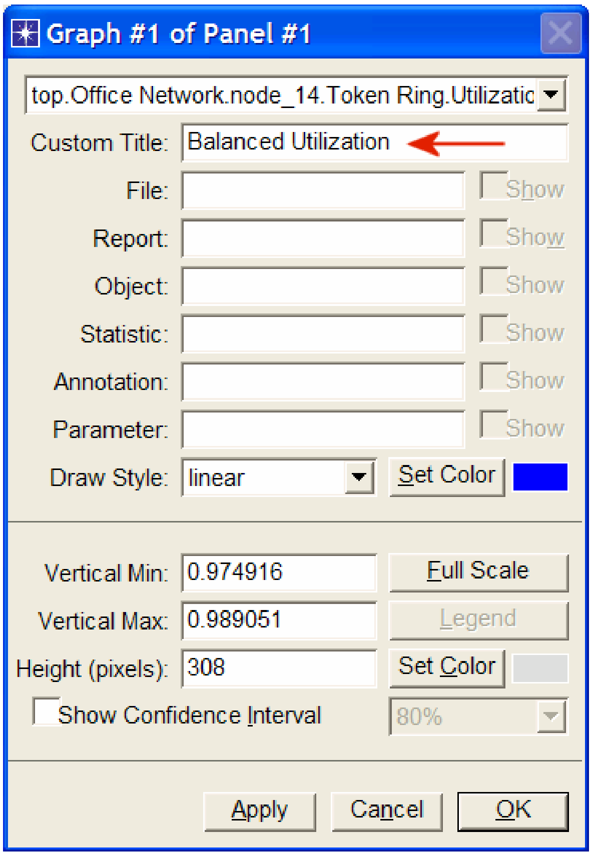
2.4.8. View the Results

To view and analyze the results.

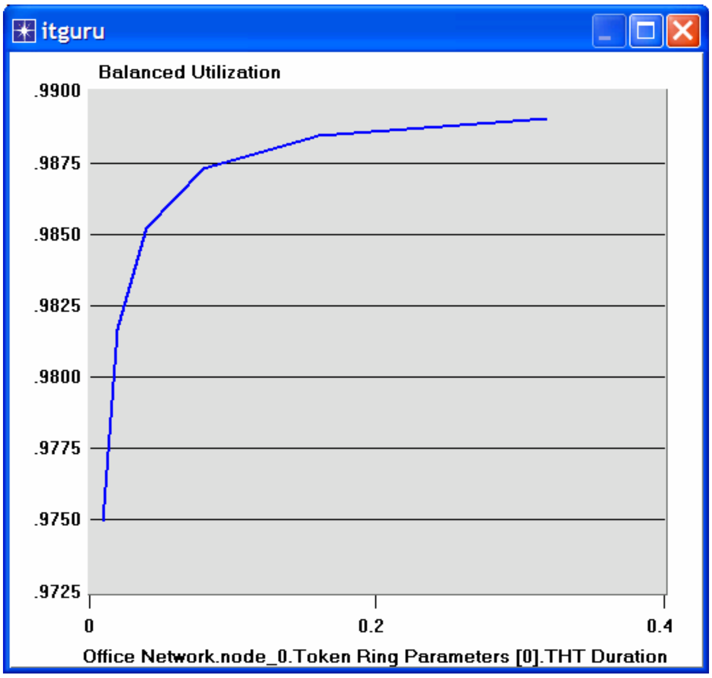
1. Select **View Results (Advanced)** from the **Results** menu. Now the **Analysis Configuration** tool is open.
2. Recall that we saved the average results in two scalar files, one for each scenario. To load the scalar file for the **Balanced** scenario, select **Load Output Scalar File** from the **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.



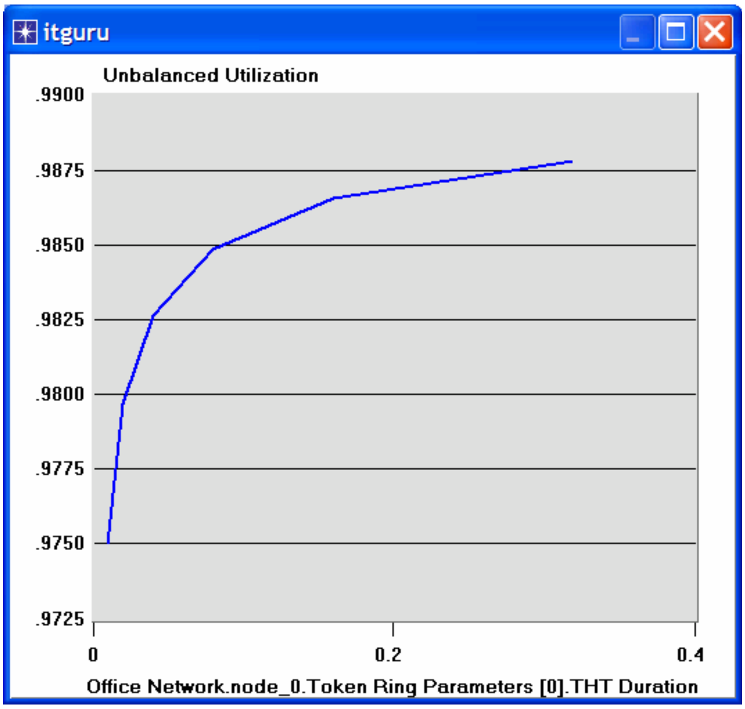
6. Click **OK**. The resulting graph should resemble the one shown below. Do not close the graph and continue with the following step.



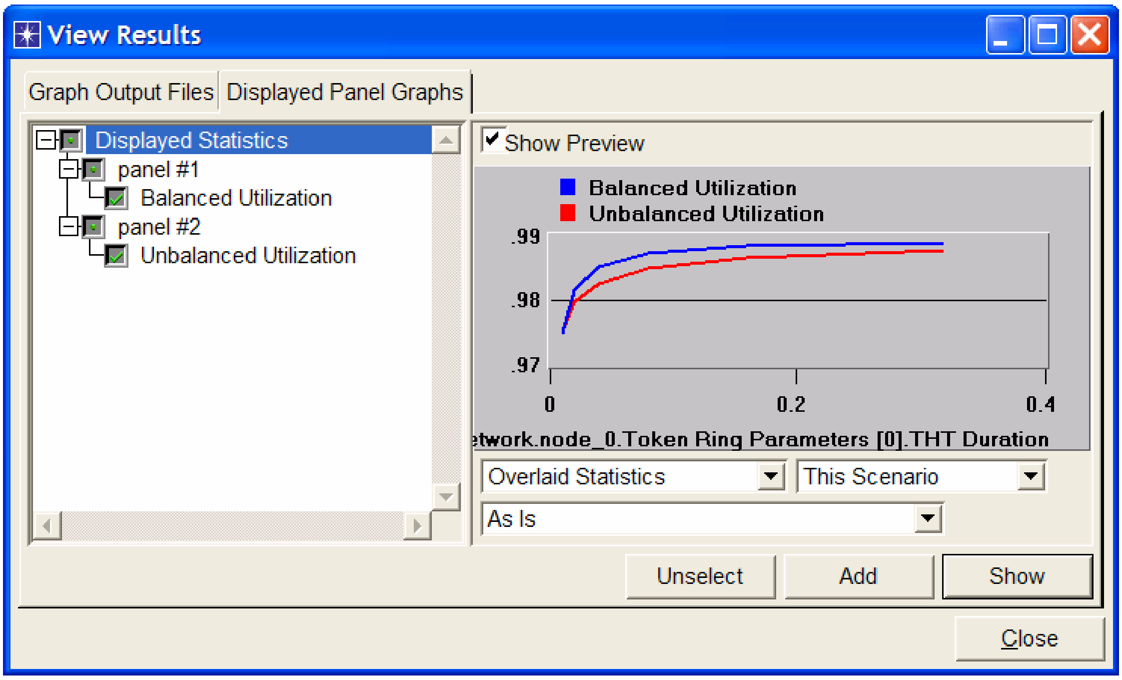
7. To compare with the **Unbalanced** scenario, load its scalar file, select **Load Output Scalar File** from the **File** menu ⇒ Select **<your initials>_Token_ Unbalanced** from the pop-up menu.

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

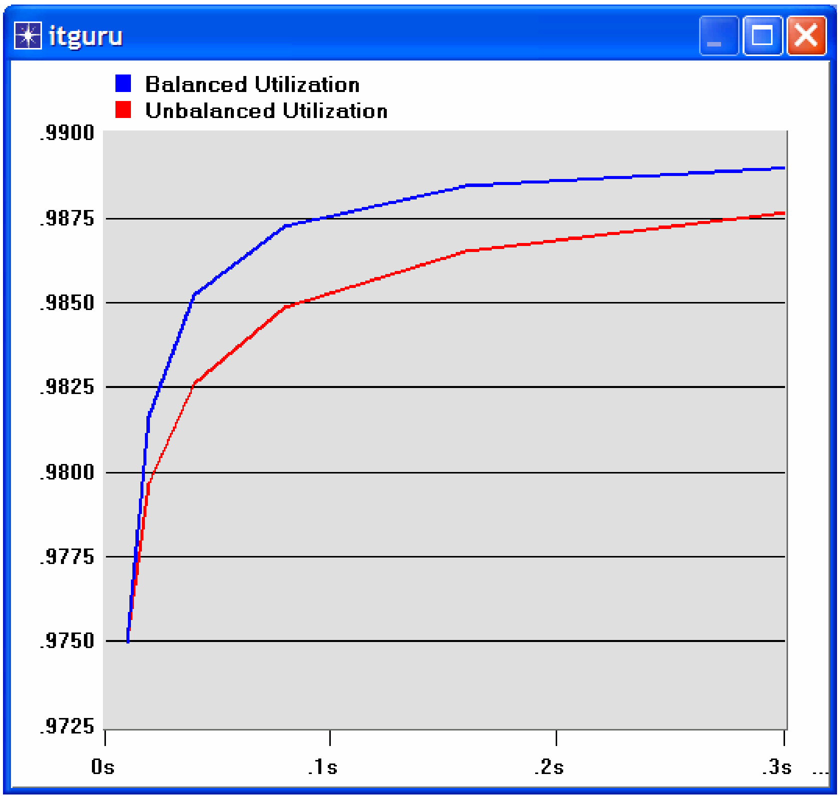
9. Click **OK** ⇒ Change the graph title to **Unbalanced** as in step 5 ⇒ Click **OK**. The resulting graph should resemble the one shown below. Do not close this graph or the previous one and continue with the following step.



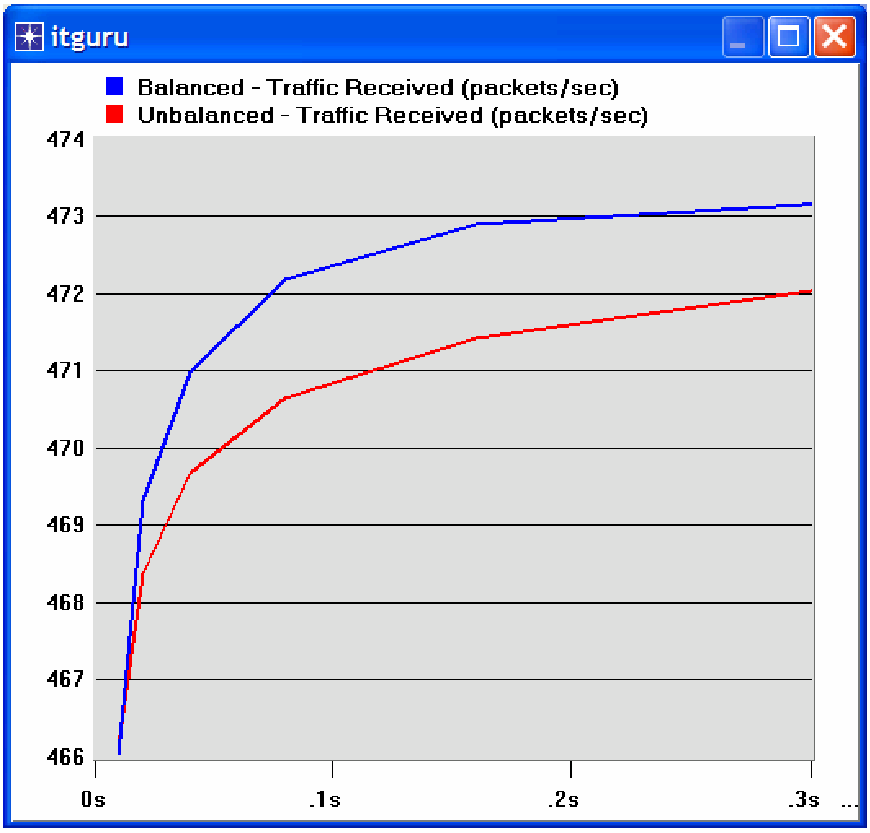
10. To combine the above two graphs on a single graph, select **Create Vector Panel** from the **Panels** menu. ⇒ Click on the **Display Panel Graphs** tab. ⇒ Select both **Balanced** and **Unbalanced** statistics. ⇒ Choose **Overlaid Statistics** from the drop-down menu in the right-bottom area of the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



2.5. *Further readings*

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

2.6. *Exercises*

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.

2.7. *Lab Report*

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

3. Laboratory - Switched LANs (A Set of Local Area Networks Interconnected by Switches)

3.1. *Objective*

This lab is designed to demonstrate the implementation of switched local area networks. The simulation in this lab will help you examine the performance of different implementations of local area networks connected by switches and hubs.

3.2. *Overview*

There is a limit to how many hosts can be attached to a single network and to the size of a geographic area that a single network can serve. Computer networks use switches to enable the communication between one host and another, even when no direct connection exists between those hosts. A switch is a device with several inputs and outputs leading to and from the hosts that the switch interconnects. The core job of a switch is to take packets that arrive on an input and forward (or switch) them to the right output so that they will reach their appropriate destination.

A key problem that a switch must deal with is the finite bandwidth of its outputs. If packets destined for a certain output arrive at a switch and their arrival rate exceeds the capacity of that output, then we have a problem of contention. In this case, the switch will queue, or buffer packets until the contention subsides. If the contention lasts too long, however, the switch will run out of buffer space and be forced to discard packets. When packets are discarded too frequently, the switch is said to be congested.

In this lab you will set up switched LANs using two different switching devices: hubs and switches. A hub forwards the packet that arrives on any of its inputs on all the outputs regardless of the destination of the packet. On the other hand, a switch forwards incoming packets to one or more outputs depending on the destination(s) of the packets. You will study how the throughput and collision of packets in a switched network are affected by the configuration of the network and the types of switching devices that are used.

3.3. *Prelab Activities*

- Read section 3.1 from ***"Computer Networks: A Systems Approach",*** 4th ***Edition.***

  Go to ***www.net-seal.net/animations.php*** and play the following animations:
  - Switch.
  - Switched Network With No Server.
  - Switched Network With Server.

3.4. *Procedure*

3.4.1. Create a New Project

1. Start the OPNET IT Guru Academic Edition ⇒ Choose New from the File menu.
2. Select Project and Click OK ⇒ Name the project **<your initials>**SwitchedLAN, and the scenario OnlyHub ⇒ 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 three times ⇒ Click OK.

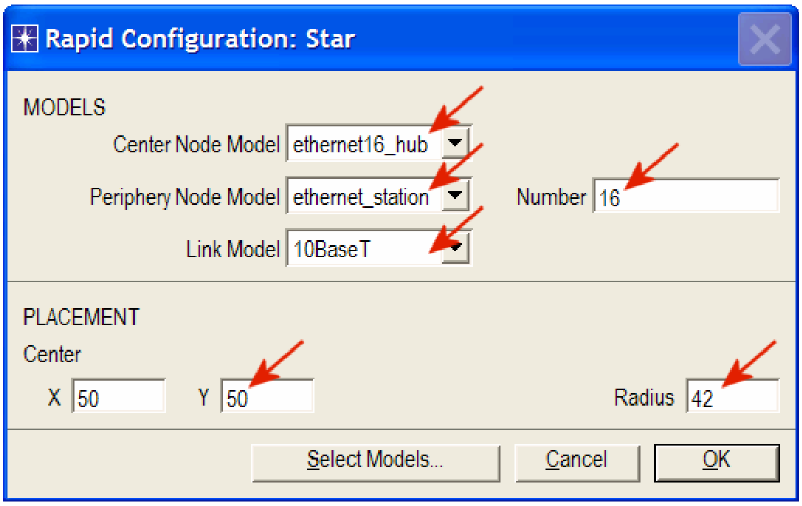
4. Close the Object Palette dialog box.

3.4.2. Create the Network

To create our switched LAN:

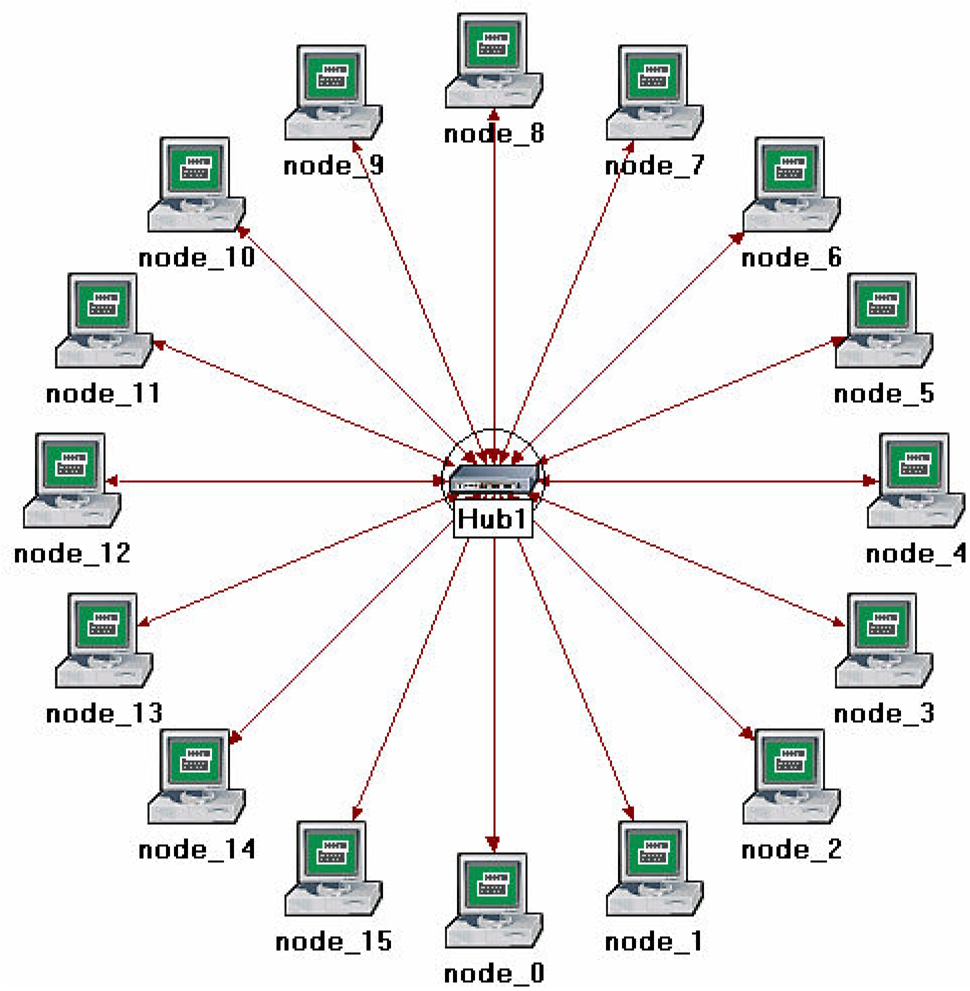
1. Select Topology ⇒ Rapid Configuration. From the drop-down menu choose Star and Click OK.
2. Click the Select Models button in the Rapid Configuration dialog box. From the Model List drop-down menu choose ethernet and Click OK.
3. In the Rapid Configuration dialog box, set the following five values: Center Node Model = ethernet16_hub, Periphery Node Model = ethernet_station, Link Model = 10BaseT, Number = 16, Y = 50, and Radius = 42 ⇒ Click OK.

The prefix **Ethernet16** indicates that the device support up to 16 Ethernet connections.



The **10BaseT** link represents an Ethernet connection operating at 10 Mbps.

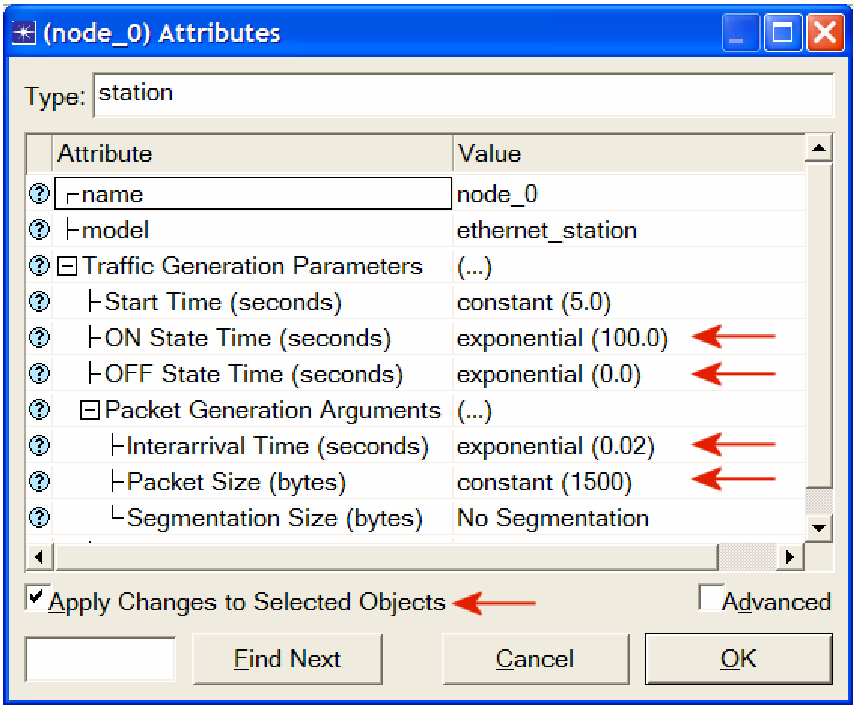
1. Right-click on node_16, which is the hub ⇒ **Edit** Attributes ⇒ Change the name attribute to Hub1 and Click OK.
2. Now that you have created the network, it should look like the following one.
3. Make sure to save your project.



3.4.3. Configure the Network Nodes

Here you will configure the traffic generated by the stations.

1. Right-click on any of the 16 stations (node_0 to node_15) ⇒ Select Similar Nodes. Now all stations in the network are selected.
2. Right-click on any of the 16 stations ⇒ **Edit** Attributes.
   a. Check the **Apply Changes to Selected Objects** check box. This is important to avoid reconfiguring each node individually.
3. Expand the hierarchies of the Traffic Generation Parameters attribute and the Packet Generation Arguments attribute ⇒ Set the following four values:
4. Click OK to close the attribute editing window(s).
5. Save your project.



3.4.4. Choose Statistics

To choose the statistics to be collected during the simulation:

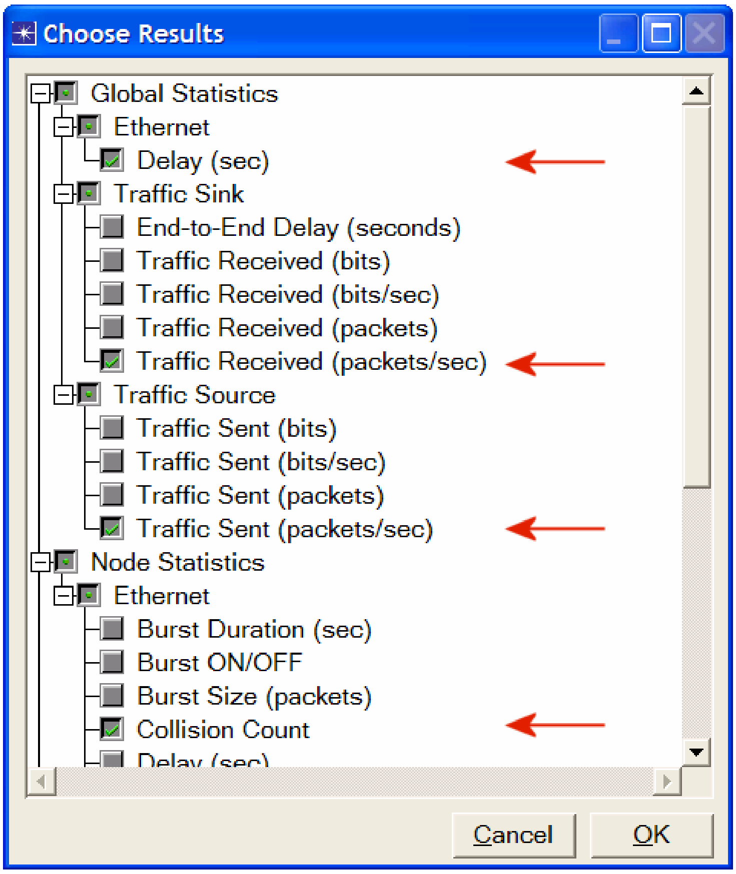
1. Right-click anywhere in the project workspace and select Choose Individual Statistics from the pop-up menu.
2. In the Choose Results dialog box, choose the following four statistics:

The **Ethernet Delay** represents the end to end delay of all packets received by all the stations.

Traffic Received (in packets/sec) by the traffic sinks across all nodes.

Traffic Sent (in packets/sec) by the traffic sources across all nodes.

Collision Count is the total number of collisions encountered by the hub during packet transmissions.



3. Click OK.

3.4.5. Configure the Simulation

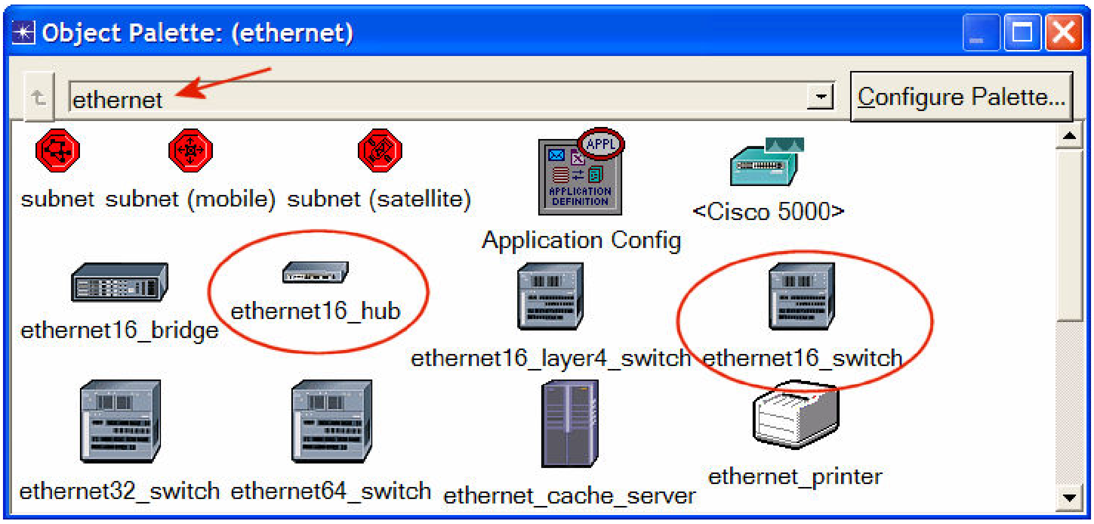
Here we need to configure the duration of the simulation:

1. Click on the Configure/Run Simulation button: 
2. Set the duration to be 2.0 minutes.
3. Click OK.

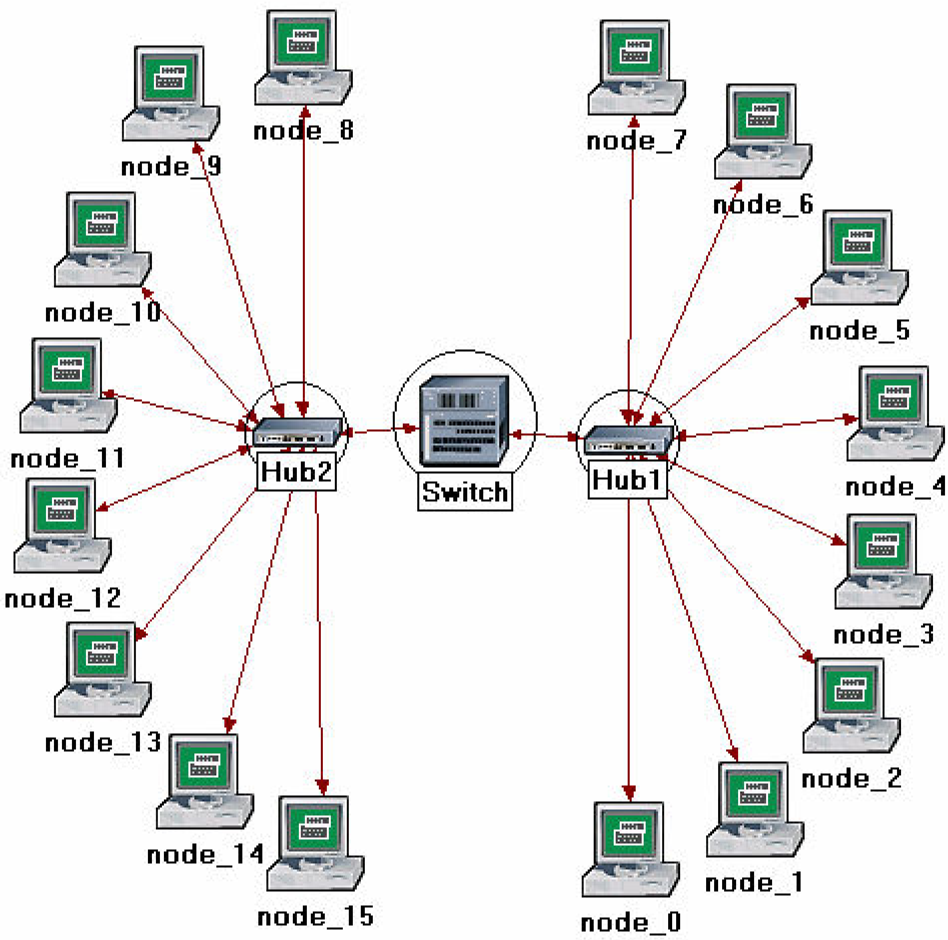
3.4.6. Duplicate the Scenario

The network we just created utilizes only one hub to connect the 16 stations. We need to create another network that utilizes a switch and see how this will affect the performance of the network. To do that we will create a duplicate of the current network:

1. Select **Duplicate Scenario** from the **Scenarios** menu and give it the name **HubAndSwitch** ⇒ Click **OK**.
2. Open the **Object Palette** by clicking on  Make sure that **Ethernet** is selected in the pull-down menu on the object palette.
3. We need to place the shown hub and switch in the new scenario.



4. To add the **Hub,** click its icon in the object palette ⇒ Move your mouse to the workspace ⇒ Click to drop the hub at a location you select. Right-click to indicate you are done deploying hub objects.
5. Similarly, add the **Switch** and then close the **Object Palette.**
6. Right-click on the new hub ⇒ **Edit Attributes** ⇒ Change the **name** attribute to **Hub2** and Click **OK**.
7. Right-click on the switch **Edit Attributes** ⇒ Change the **name** attribute to **Switch** and Click **OK**.
8. Reconfigure the network of the **HubAndSwitch** scenario so that it looks like the following one.



Hints:

b. To remove a link, select it and choose **Cut** from the **Edit** menu (or simply hit the **Delete** key). You can select multiple links and delete all of them at once.

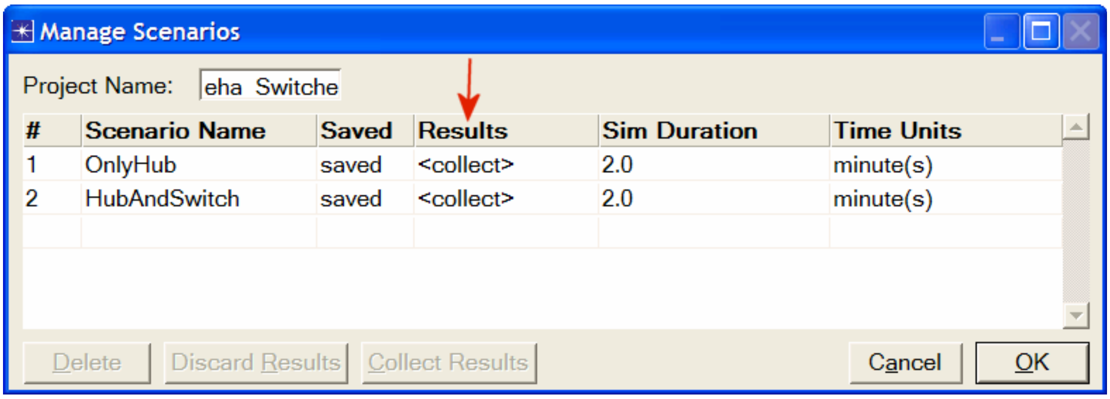
c. To add a new link, use the **10BaseT** link available in the **Object Palette**.

9. Save your project.

3.4.7. Run the Simulation

To run the simulation for both scenarios simultaneously:

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

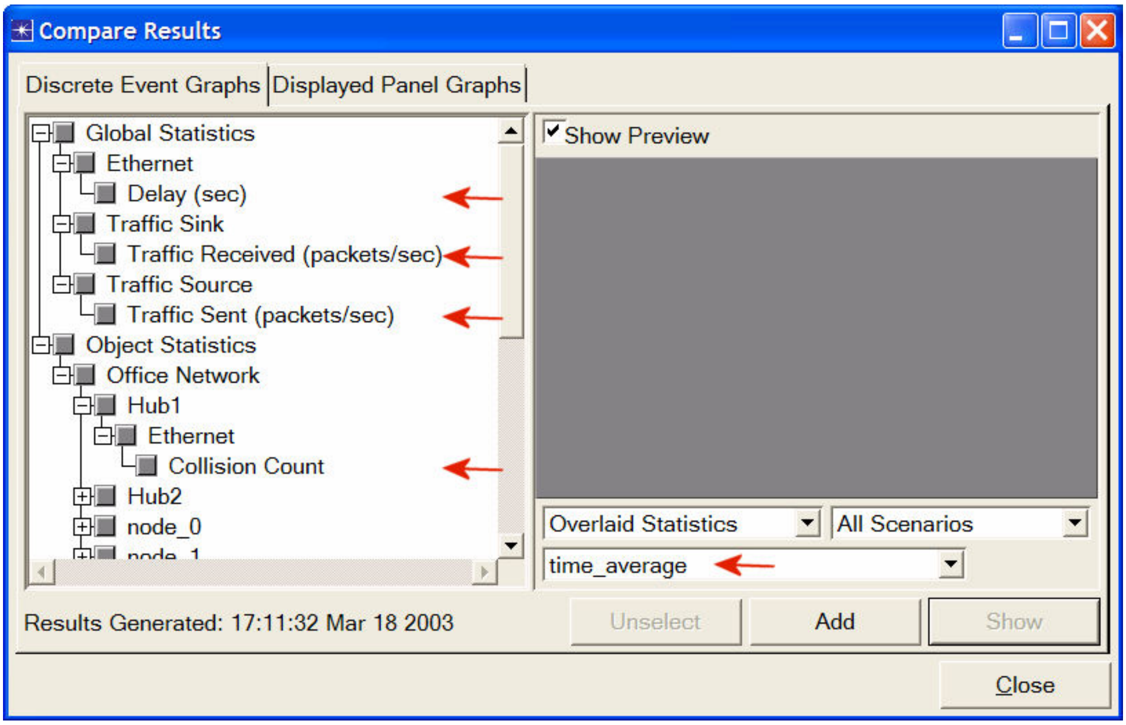


3. Click **OK** to run the two simulations. Depending on the speed of your processor, this may take several minutes to complete.
4. After the two simulation runs complete, one for each scenario, click **Close**.
5. Save your project.

3.4.8. View the Results

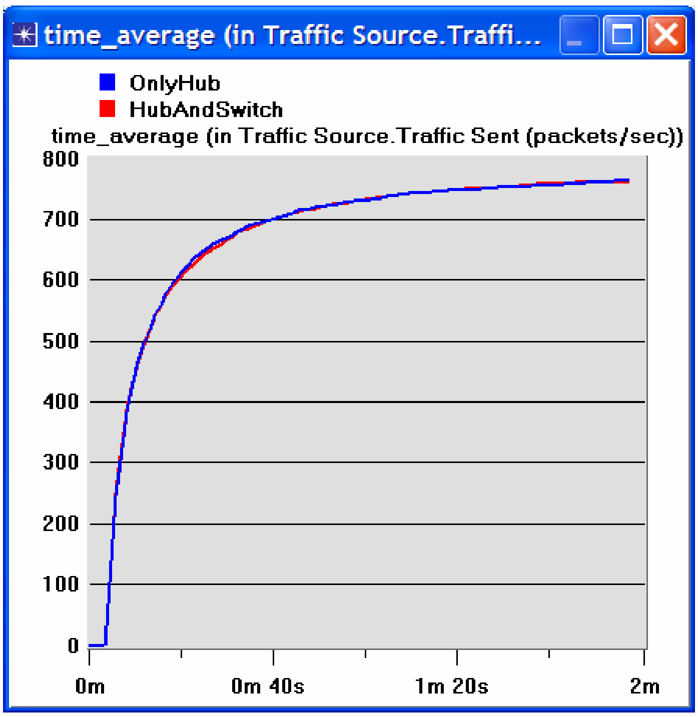
To view and analyze the results:

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

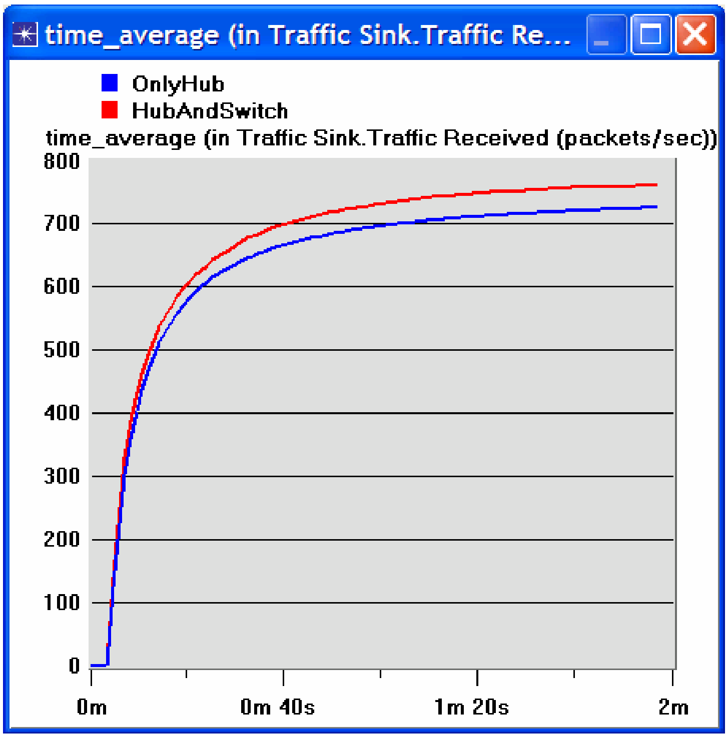


time_average is the average value over time of the values generated during the collection windows. This average is performed assuming a "sample-and-hold" behavior of the data set (i.e., each value is weighted by the amount of time following update and the sum of all the weighted values is divided by the width of the collection window). For example, suppose you have a 1-second bucket in which 10 values have been generated. The first 7 values were generated between 0 and 0.3 seconds, the 8th value at 0.4 seconds, the 9th value at 0.6 seconds, and the 10th at 0.99 seconds. Because the last 3 values have higher durations, they are weighted more heavily in calculating the **time average**.

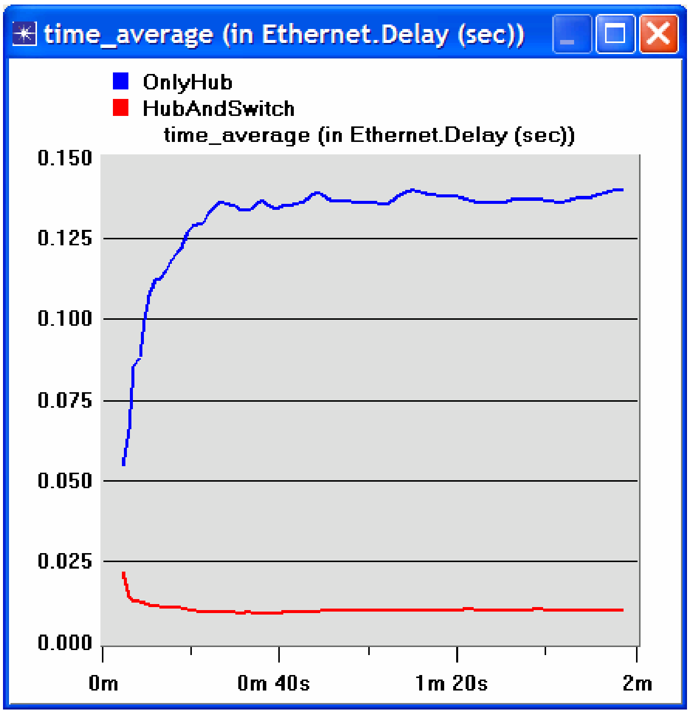
3. Select the **Traffic Sent (packets/sec)** statistic and click **Show.** The resulting graph should resemble the one below. As you can see, the traffic sent in both scenarios is almost identical.



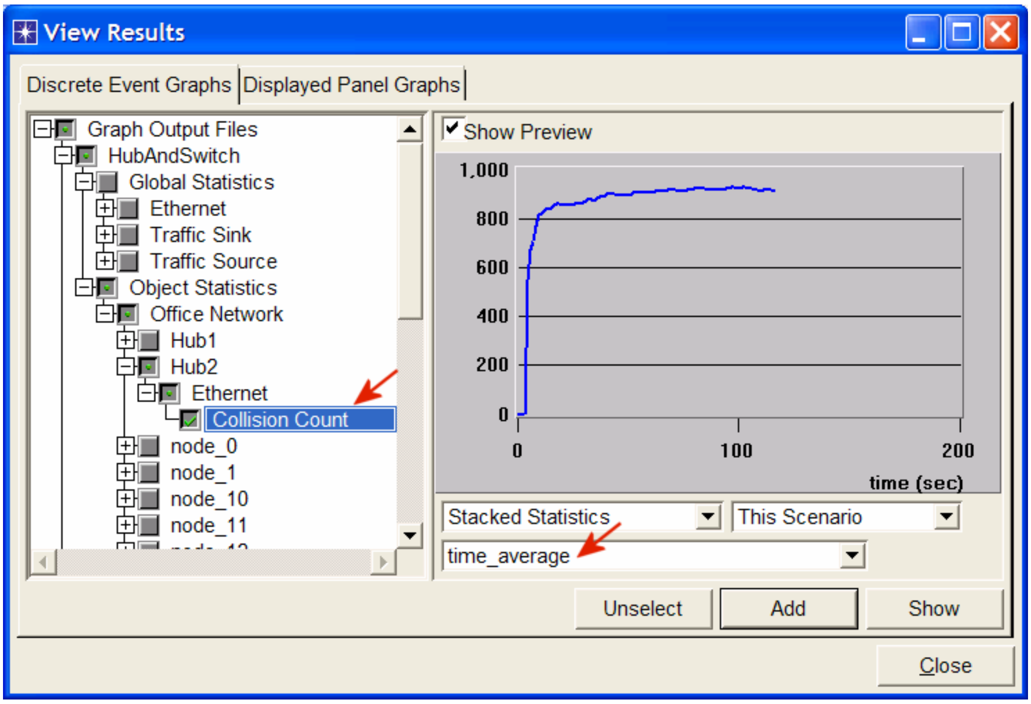
Select the **Traffic Received (packets/sec)** statistic and click **Show.** The resulting graph should resemble the one below. As you see, the traffic received with the second scenario, **HubAndSwitch**, is higher than that of the **OnlyHub** scenario.



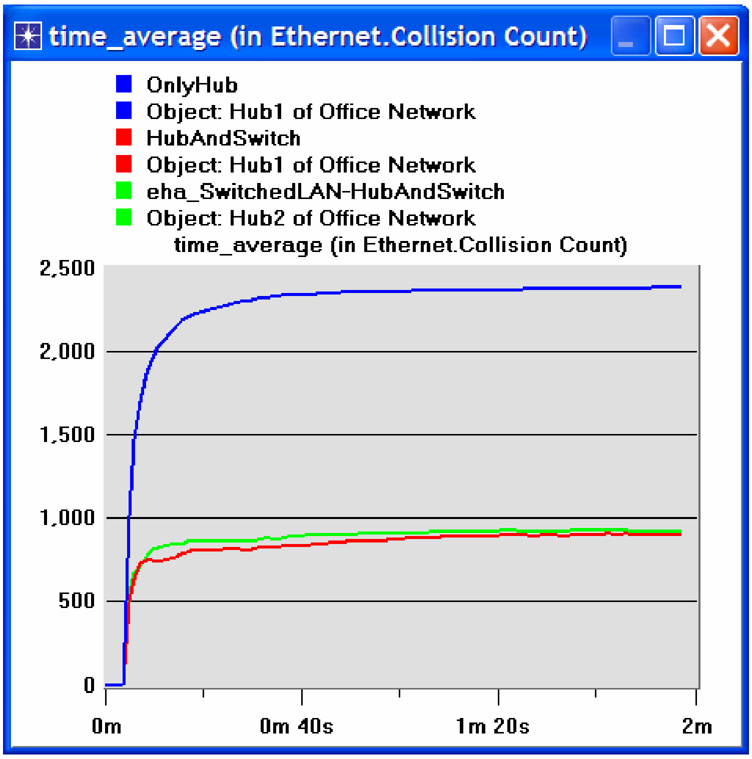
4. Select the **Delay (sec)** statistic and click **Show**. The resulting graph should resemble the one below. (Note: Result may vary slightly due to different node placement.)



5. Select the **Collision Count** statistic for **Hub1** and click **Show**.
6. On the resulting graph right-click anywhere on the graph area ⇒ Choose **Add Statistic** ⇒ Expand the hierarchies as shown below ⇒ Select the **Collision Count** statistic for **Hub2**⇒ Change **As Is** to **time_average** ⇒ Click **Add**.



7. The resulting graph should resemble the one below.



8. Save your project.

3.5. *Further readings*

- OPNET Building Network Topologies: From the **Protocols** menu, select **Methodologies** ⇒ Building Network Topologies.

3.6. *Exercises*

1) Explain why adding a switch makes the network perform better in terms of throughput and delay.

2) We analyzed the collision counts of the hubs. Can you analyze the collision count of the "Switch"? Explain your answer.

3) Create two new scenarios. The first one is the same as the **OnlyHub** scenario but replace the hub with a switch. The second new scenario is the same as the **HubAndSwitch** scenario but replace both hubs with two switches, remove the old switch, and connect the two switches you just added together with a **10BaseT** link. Compare the performance of the four scenarios in terms of delay, throughput, and collision count. Analyze the results. Note: To replace a hub with a switch, right-click on the hub and assign **ethernet16_switch** to its **model** attribute.

3.7. *Lab Report*

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

4. Laboratory - Network Design (Planning a Network with Different Users, Hosts, and Services)

4.1. *Objective*

The objective of this lab is to demonstrate the basics of designing a network, taking into consideration the users, services, and locations of the hosts.

4.2. *Overview*

Optimizing the design of a network is a major issue. Simulations are usually used to analyze the conceptual design of the network. The initial conceptual design is usually refined several times until a final decision is made to implement the design. The objective is to have a design that maximizes the network performance, taking into consideration the cost constraints and the required services to be offered to different types of users. After the network has been implemented, network optimization should be performed periodically throughout the lifetime of the network to ensure maximum performance of the network and to monitor the utilization of the network resources.

In this lab you will design a network for a company that has four departments: Research, Engineering, E-Commerce, and Sales. You will utilize a LAN model that allows you to simulate multiple clients and servers in one simulation object. This model dramatically reduces both the amount of configuration work you need to perform and the amount of memory needed to execute the simulation. You will be able to define a profile that specifies the pattern of applications employed by the users of each department in the company. By the end of this lab, you will be able to study how different design decisions can affect the performance of the network.

4.3. *Prelab Activities*

- Read section 3.2 from *"Computer Networks: A Systems Approach"*, 4th *Edition.*

Go to ***www.net-seal.net/animations.php*** and play the following animations:

- Adding Switches.

4.4. *Procedure*

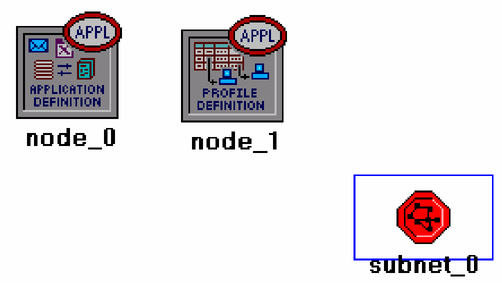
4.4.1. Create a New Project

1. Start **OPNET IT Guru Academic Edition** ⇒ Choose **New** from the **File** menu.
2. Select **Project** and Click **OK** ⇒ Name the project **<your initials>_NetDesig**, and the scenario **SimpleNetwork** ⇒ Click **OK**.
3. In the *Startup Wizard Initial Topology* dialog box, make sure that **Create Empty Scenario** is selected ⇒ Click **Next** ⇒ Choose **Campus** from the *Network Scale* list ⇒ Click **Next** ⇒ Choose **Miles** from the **Size** drop-down menu and assign **1** for both **X Span** and **Y Span** ⇒ Click **Next** twice ⇒ Click **OK**.

4.4.2. Create and Configure the Network

4.4.2.1. Initialize the 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 **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: **Application Config, Profile Config,** and a **subnet**.
   a. To add an object from palette, click its icon on the object palette. ⇒ Move your mouse to the workspace. ⇒ Left click to place the object. Right-click when finished. The workplace should contain the following three objects:



3. Close the *Object Palette* dialog box and save your project.

Application Config is used to specify application that will be used to configure user's profiles.

Profile Config describes the activity patterns of a user or group of users in terms of the applications used over a period of time. You must define the applications using the **Application Config** object between using this object

4.4.2.2. Configure the Services:

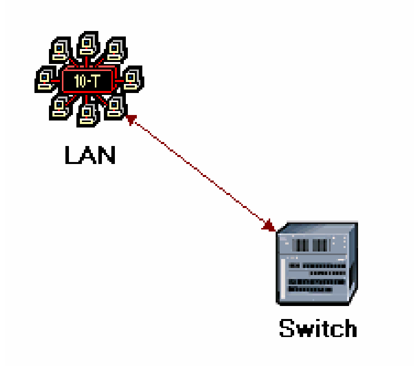
1. Right-click on the **Application Config** node ⇒ **Edit Attributes** Change the **name** attribute to **Applications** ⇒ Change the **Application Definitions** attribute to **Default** ⇒ Click **OK**.
2. Right-click on the **Profile Config node** ⇒ **Edit Attributes** ⇒ Change the **name** attribute to **Profiles** ⇒ Change the **Profile Configuration** attribute to **Sample Profiles** ⇒ Click **OK**.
3. **Sample Profiles** provides patterns of applications employed by users such as engineers, researchers, salespeople, and multimedia users.

4.4.2.3. Configure a Subnet:

1. Right-click on the **subnet** node ⇒ **Edit Attributes** ⇒ Change the **name** attribute to **Engineering** and Click **OK**.
2. Double-click on the **Engineering** node. You get an empty workspace, indicating that the subnet contains no objects.
3. Open the object palette  and make sure it is still set to **internet_toolbox**.
4. Add the following items to the subnet workspace: **10BaseT LAN**, **ethernet16_Switch**, and a **10BaseT** link to connect the LAN with the Switch ⇒ Close the palette.

5. Right-click on the **10BaseT LAN** node ⇒ **Edit Attributes** ⇒ Change the **name** attribute to LAN Observe that the **Number of Workstations** attribute has a value of 10 Click in the **Value** column for the **Application: Supported Profiles** attribute, and select **Edit**. You should get a table in which you should do the following:
    a. Set the number of **rows** to **1.**
    b. Set the **Profile Name** to **Engineer.** *Note:* **Engineer** is one of the "sample" profiles provided within the **Profile Config** object.
    c. Click **OK** twice.

    The object we just created is equivalent to a 10-workstation star topology LAN. The traffic generated from the users of this LAN resembles that generated by "engineers."
6. Rename the **ethernet16_Switch** to **Switch**.
7. The subnet should look like the shown one.
8. Save your project.

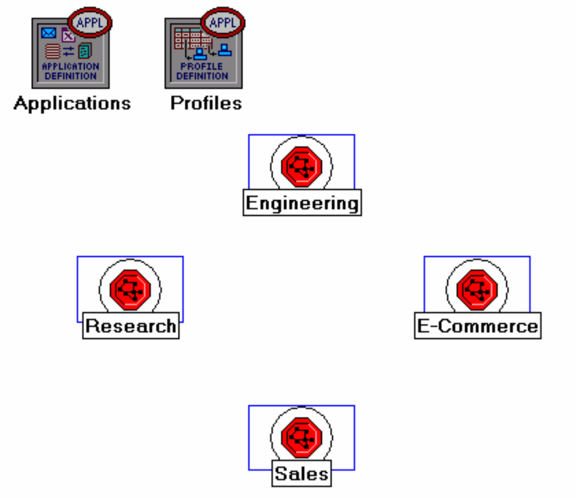


4.4.2.4. Configure All Departments:

1. Now you have completed the configuration of the Engineering department subnet. To go back to the main project space, click the **Go to the higher level**  button.

The subnets of the other departments in the company should be similar to the engineering one except for the supported profiles.

2. Make three copies of the **Engineering** subnet we just created: Click on the **Engineering** node ⇒ From the **Edit** menu, select **Copy.** From the **Edit** menu, select **Paste** three times, placing the subnet in the workspace after each, to create the new subnets.
3. Rename (right-click on the subnet and select Set **Name)** and arrange the subnets as shown bellow:

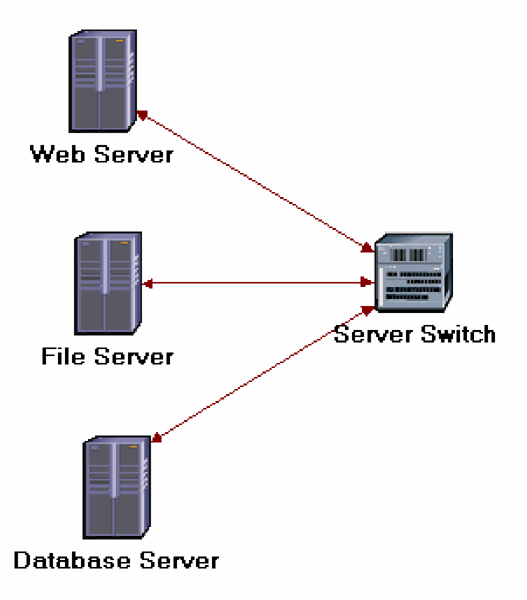


4. Double-click the **Research** node ⇒ **Edit** the attributes of its **LAN** ⇒ **Edit** the value of the **Application: Supported Profiles** attribute. ⇒ Change the value of the **Profile Name** from **Engineer** to **Researcher** ⇒ Click **OK** twice ⇒ **Go to the higher level** by clicking the  button.
5. Repeat step 4 with the **Sales** node and assign to its **Profile Name** the profile **Sales Person.**
6. Repeat step 4 with the **E-commerce** node and assign to its **Profile Name** the profile **E-commerce Customer.**
7. Save your project.

4.4.2.5. Configure the Servers:

Now we need to implement a subnet that contains the servers. The servers have to support the applications defined in the profiles we deployed. You can double-check those applications by editing the attributes of our **Profile** node. Inspect each row under the **Applications** hierarchy, which in turn, is under the **Profile Configuration** hierarchy. You will see that we need servers that support the following applications: Web browsing, Email, Telnet, File Transfer, Database, and File Print.

1. Open the **Object Palette**  and add a new **subnet** ⇒ Rename the new subnet to **Servers** ⇒ Double-click the **Servers** node to enter its workspace.
2. From the **Object Palette,** add three **ethernet_servers,** one **ethernet16_switch** and three **10BaseT** links to connect the servers with the switch.
3. Close the **Object Palette.**
4. Rename the servers and the switch as follows:



5. Right-click on each one of the above servers and **Edit** the value of the **Application: Supported Services** attribute.
   i. For the *Web Server* add four rows to support the following services: **Web Browsing (Light HTTP1.1) Web Browsing (Heavy HTTP1.1), Email (Light),** and **Telnet Session (Light)**.
   ii. For the *File Server* add two rows to support the following services: **File Transfer (Light)** and **File Print (Light)**.
   iii. For the *Database Server* add one row to support the following service: **Database Access (Light)**.

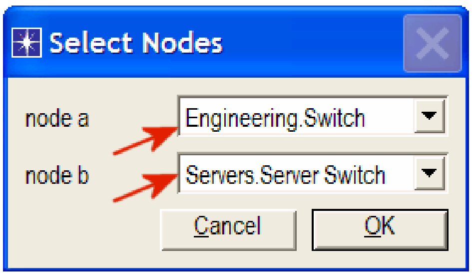
6. Go back to the project space by clicking the **Go to the higher level**  button.
7. Save your project.

4.4.2.6. Connect the Subnets:

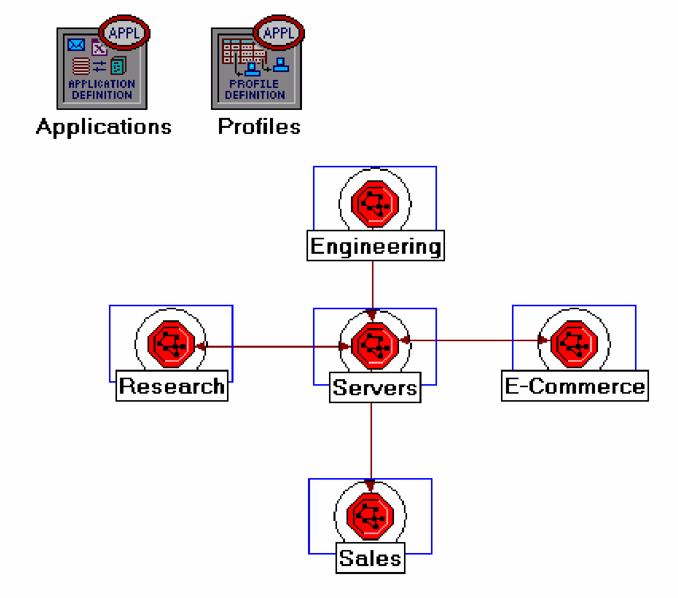
Now all subnets are ready to be connected together.

1. Open the **Object Palette**  and add four **100BaseT** links to connect the subnets of the departments to the Servers subnet.

   As you create each link, make sure that it is configured to connect the "switches" in both subnets to each other. Do this by choosing them from the drop-down menus as follows:



2. Close the **Object Palette**.
3. Now your network should resemble the following one:

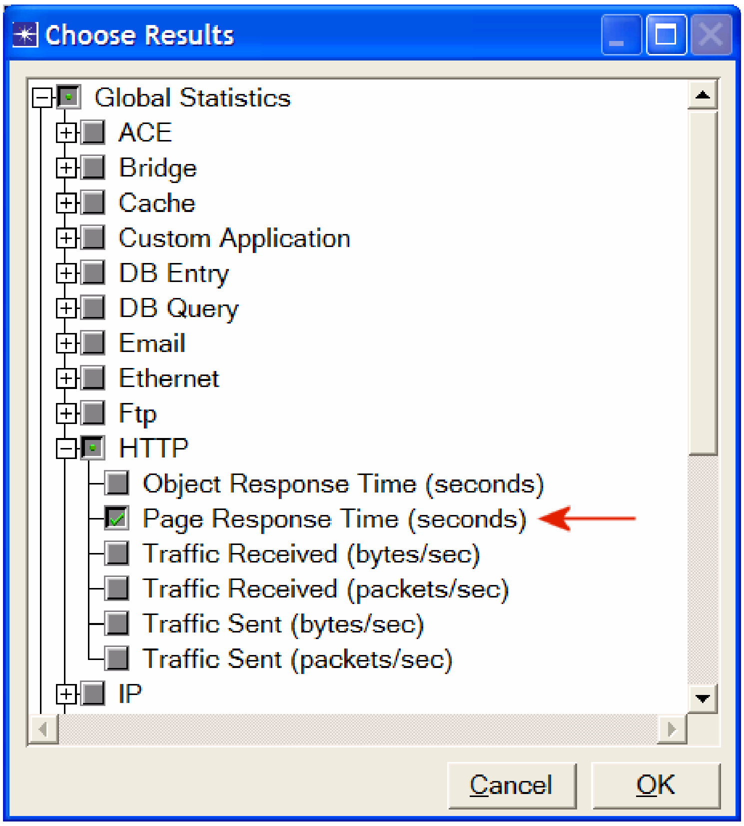


4. Save your project.

4.4.2.7. Choose the Statistics

To test the performance of our network we will collect one of the many 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, choose the following statistic:



Page Response Time is the required time to retrieve the entire page.

3. Click **OK**.

4.4.3. Configure the Simulation

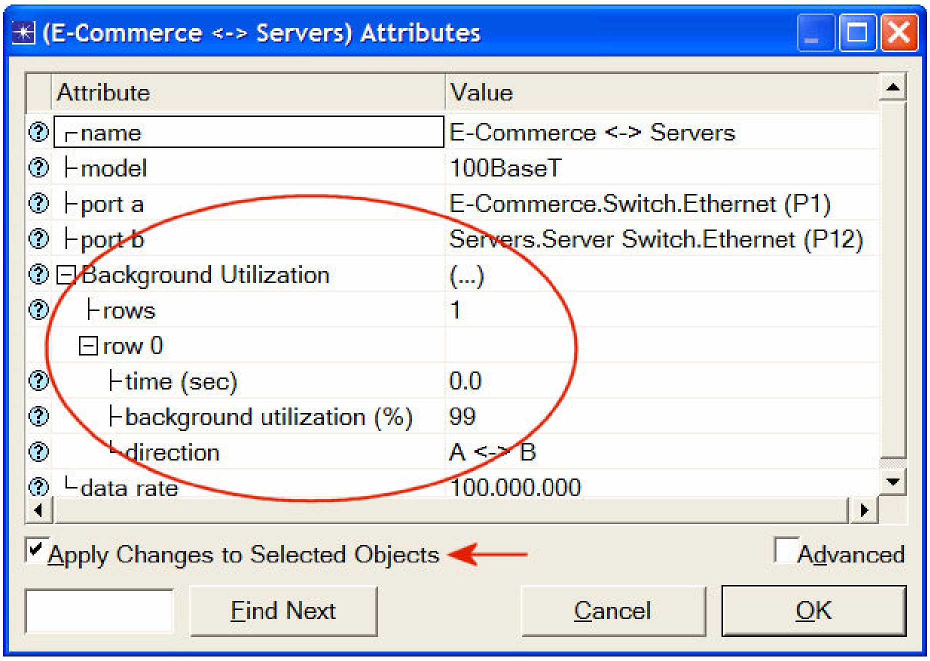
Here we need to configure the duration of the simulation:

1. Click on the **Configure/Run Simulation**  button.
2. Set the duration to be **30.0 minutes**.
3. Press **OK**.

4.4.4. Duplicate the Scenario

In the network we just created we assumed that there is no background traffic already in the links. In real networks, the links usually have some existing background traffic. We will create a duplicate of the **SimpleNetwork** scenario but with background utilization in the **100BaseT** links.

1. Select **Duplicate Scenario** from the **Scenarios** menu and give it the name **BusyNetwork** ⇒ Click **OK**.
2. Select all the **100BaseT** links simultaneously (click on all of them while holding the **Shift** key) ⇒ Right-click on anyone of them ⇒ **Edit Attributes** ⇒ Check the **Apply Changes to Selected Objects** check box.
3. Expand the hierarchy of the **Background Utilization** attribute ⇒ Expand the **row 0** hierarchy ⇒ Assign **99** to the **background utilization (%)** as shown below.



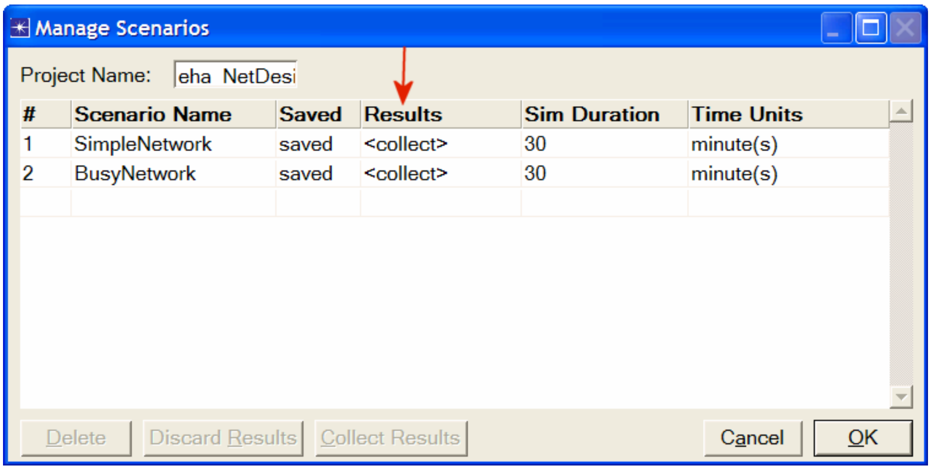
4. Click **OK**.

Link utilization is the percentage of the used link bandwidth.

4.4.5. 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.

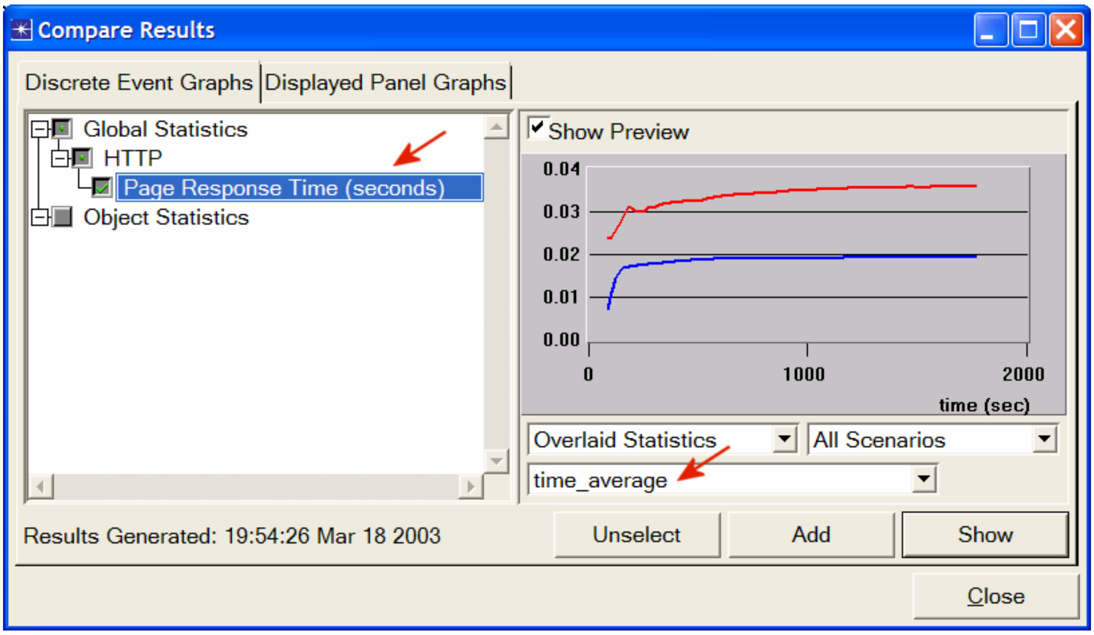


3. Click **OK** to run the two simulations. Depending on the speed of your processor, this may take several seconds to complete.
4. After the two simulation runs complete (one for each scenario), click **Close**.
5. Save your project.

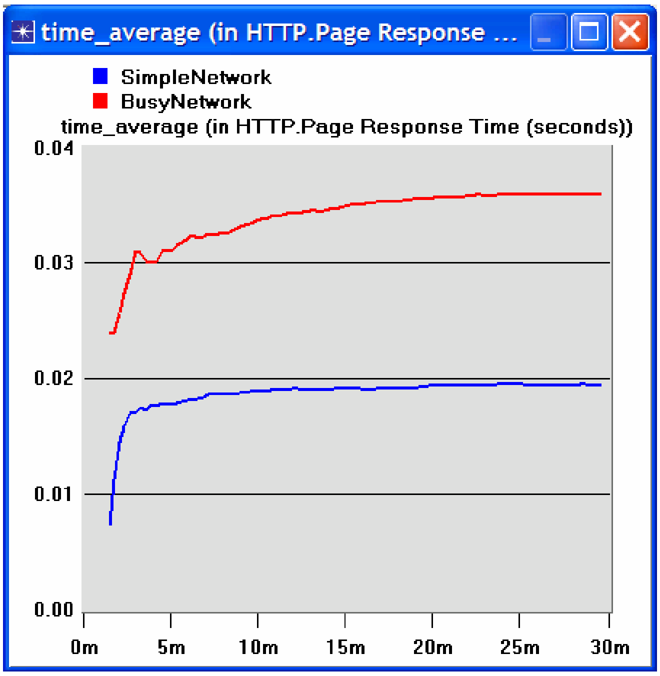
4.4.6. View the Results

To view and analyze the results:

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



3. Select the **Page Response Time (seconds)** statistic and click **Show**. The resulting graph should resemble the one below. (Note: Results may vary slightly due to different node placement.)



4.5. *Further readings*

- OPNET Configuring Applications and Profiles: From the **Protocols** menu, select **Applications** ⇒ **Model Usage Guide** ⇒ Configuring Applications and Profiles.

4.6. *Exercises*

1) Analyze the result we obtained regarding the HTTP page response time. Collect four other statistics, of your choice, and rerun the simulation of the *Simple* and the *Busy* network scenarios. Get the graphs that compare the collected statistics. Comment on these results.

2) In the **BusyNetwork** scenario, study the **utilization%** of the CPUs in the servers (Right-click on each server and select **Choose Individual Statistics** ⇒ **CPU** ⇒ **Utilization**).

3) Create a new scenario as a duplicate of the **BusyNetwork** scenario. Name the new scenario **Q3_OneServer**. Replace the three servers with only one server that supports all required services. Study the **utilization%** of that server's CPU. Compare this utilization with the three CPU utilizations you obtained in the previous exercise.

4) Create a new scenario as a duplicate of the **BusyNetwork** scenario. Name the new scenario **Q4_FasterNetwork**. In the **Q4_FasterNetwork** scenario, replace all **100BaseT** links in the network with **10Gbps Ethernet** links and replace all **10BaseT** links with **100BaseT** links. Study how increasing the bandwidth of the links affects the performance of the network in the new scenario (e.g., compare the HTTP page response time in the new scenario with that of the **BusyNetwork**).

4.7. *Lab Report*

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

5. Laboratory - ATM (A Connection-Oriented, Cell-Switching Technology)

5.1. *Objective*

The objective of this lab is to examine the effect of ATM adaptation layers and service classes on the performance of the network.

5.2. *Overview*

Asynchronous Transfer Mode (ATM) is a connection-oriented, packet-switched technology. The packets that are switched in an ATM network are of a fixed length, 53 bytes, and are called ***cells.*** The cell size has a particular effect on carrying voice traffic effectively. The ATM Adaptation Layer (AAL) sits between ATM and the variable-length packet protocols that might use ATM, such as IP. The AAL header contains the information needed by the destination to reassemble the individual cells back into the original message. Because ATM was designed to support all sorts of services, including voice, video, and data, it was felt that different services would have different AAL needs. AAL1 and AAL2 were designed to support applications, like voice, that require guaranteed bit rates. AAL3/4 and AAL5 provide support for packet data running over ATM.

ATM provides QoS capabilities through its five service classes: CBR, VBR-rt VBR-nrt, ABR, and UBR. With CBR (constant bit rate), sources transmit stream traffic at a fixed rate. CBR is well-suited for voice traffic that usually requires circuit switching. Therefore, CBR is very important to telephone companies. UBR, unspecified bit rate, is ATM's best-effort service. There is one small difference between UBR and the best-effort model. Because ATM always requires a signaling phase before data is sent, UBR allows the source to specify a maximum rate at which it will send. Switches may make use of this information to decide whether to admit or reject the new VC (virtual circuit).

In this lab you will set up an ATM network that carries three applications: Voice, Email, and FTP. You will study how the choice of the adaptation layer as well as the service classes can affect the performance of the applications.

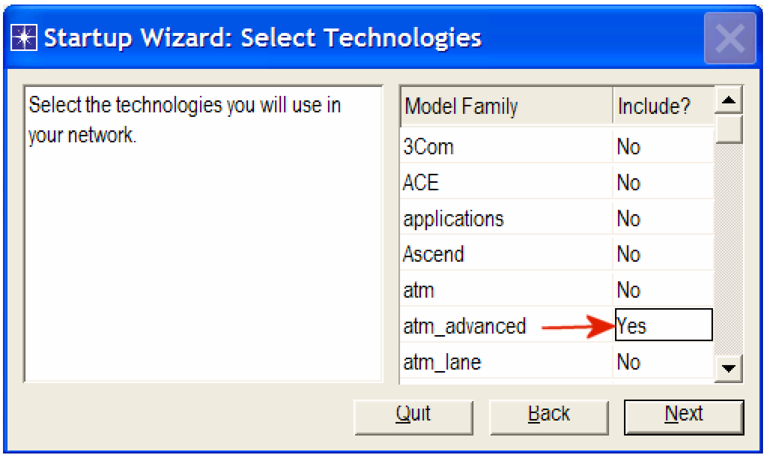
5.3. *Prelab Activities*

- Read section 3.3 from *"Computer Networks: A Systems Approach",* 4th *Edition.*

5.4. *Procedure*

5.4.1. 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>_ATM**, and the scenario **CBR_UBR** ⇒ 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 maps ⇒ Click **Next** ⇒ From the *Select Technologies* list, include the **atm_advanced** Model Family as shown in the following figure ⇒ Click **Next** ⇒ Click **OK**.

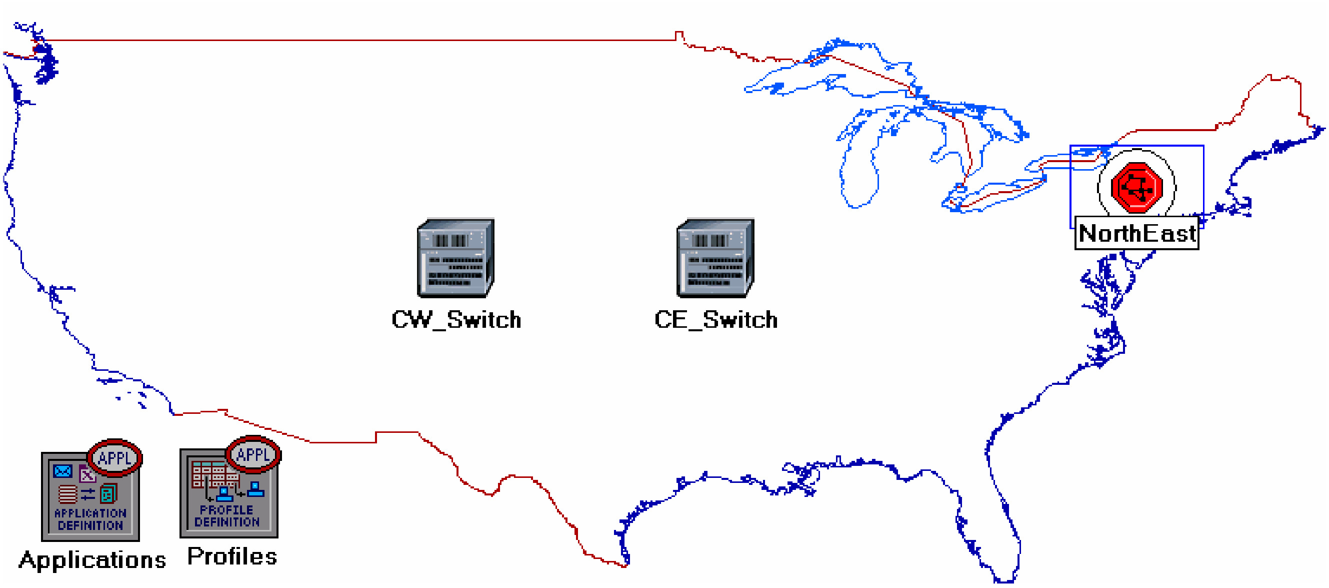


5.4.2. Create and Configure the Network

5.4.3. Initialize the Network:

1. The *Object Palette* dialog box should now be on the top of your project workspace. If it is not there, open it by clicking . Make sure that **atm_advanced** is selected from the pull-down menu on the object palette.
2. Add to the project work space the following objects from the palette: **Application Config**, **Profile Config**, two **atm8_crossconn_adv** switches, and a **subnet**.

   b. To add an object from a palette, click its icon in the object palette ⇒ Move your mouse to the workspace and click to place the object ⇒ Right-click to get out of "object creation mode."
3. Close the *Object Palette* dialog box and rename (right-click on the node ⇒ Set **Name**) the objects you added as shown and then save your project:



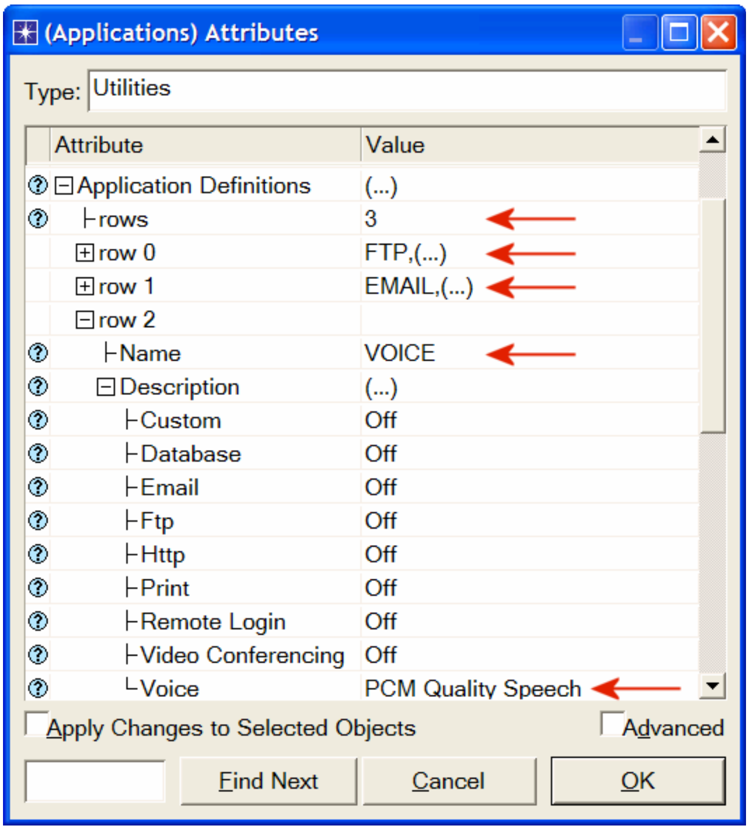
5.4.3.1. Configure the Applications:

1. Right-click on the **Applications** node ⇒ **Edit Attributes** Expand the **Application Definitions** attribute and set **rows** to **3** ⇒ Name the rows: **FTP, EMAIL,** and **VOICE**.

   i. Go to the **FTP** row ⇒ Expand the **Description** hierarchy ⇒ Assign **High Load** to **FTP**.

ii. Go to the **EMAIL** row ⇒ Expand the **Description** hierarchy ⇒ Assign **High Load** to Email.

iii. Go to the **VOICE** row ⇒ Expand the **Description** hierarchy ⇒ Assign **PCM Quality Speech** to **Voice**.



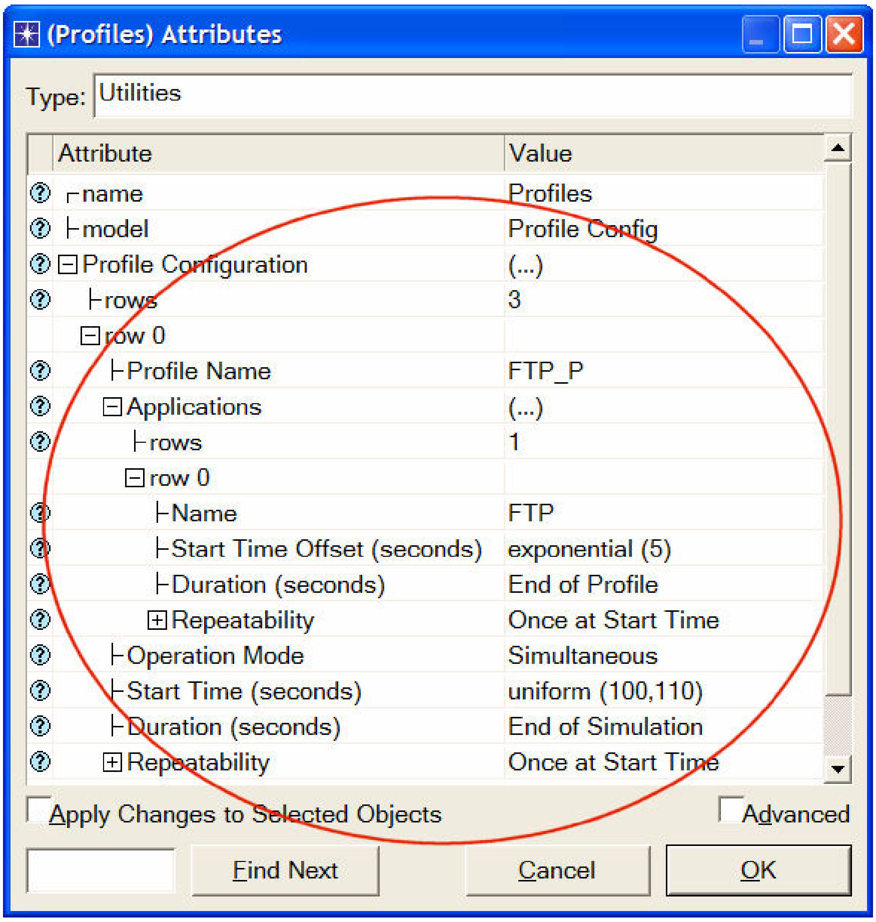
2. Click **OK** and then save your project

PCM stands for Pulse Code Modulation. It is a procedure used to digitize speech before transmitting it over the network.

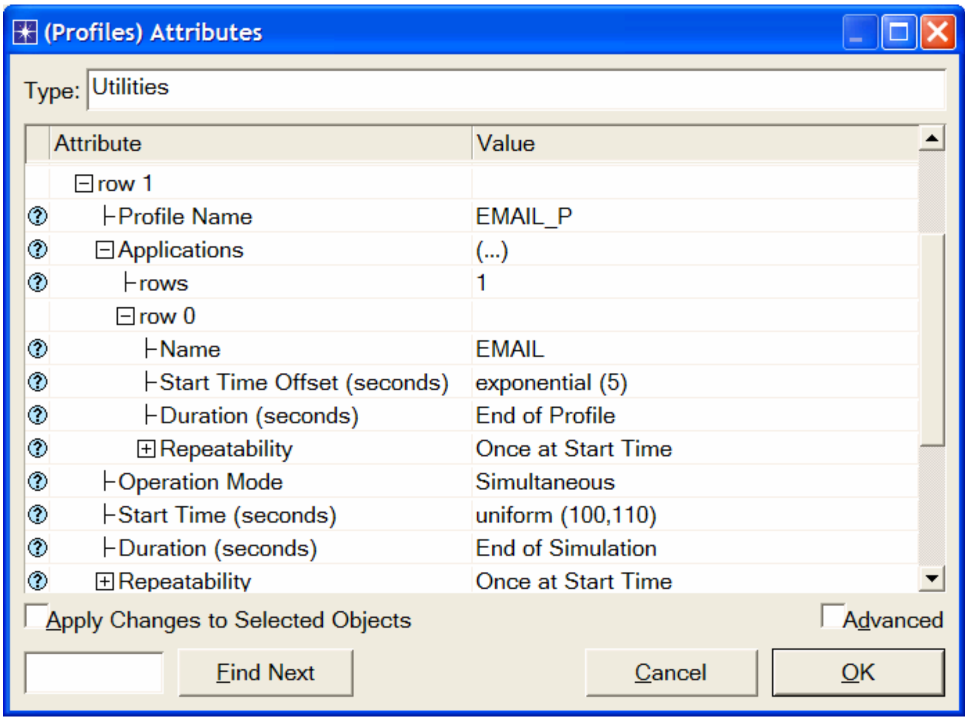
5.4.3.2. Configure the Profiles:

1. Right-click on the **Profiles** node ⇒ **Edit Attributes**, Expand the **Profile Configuration** attribute and set **rows** to **3**.

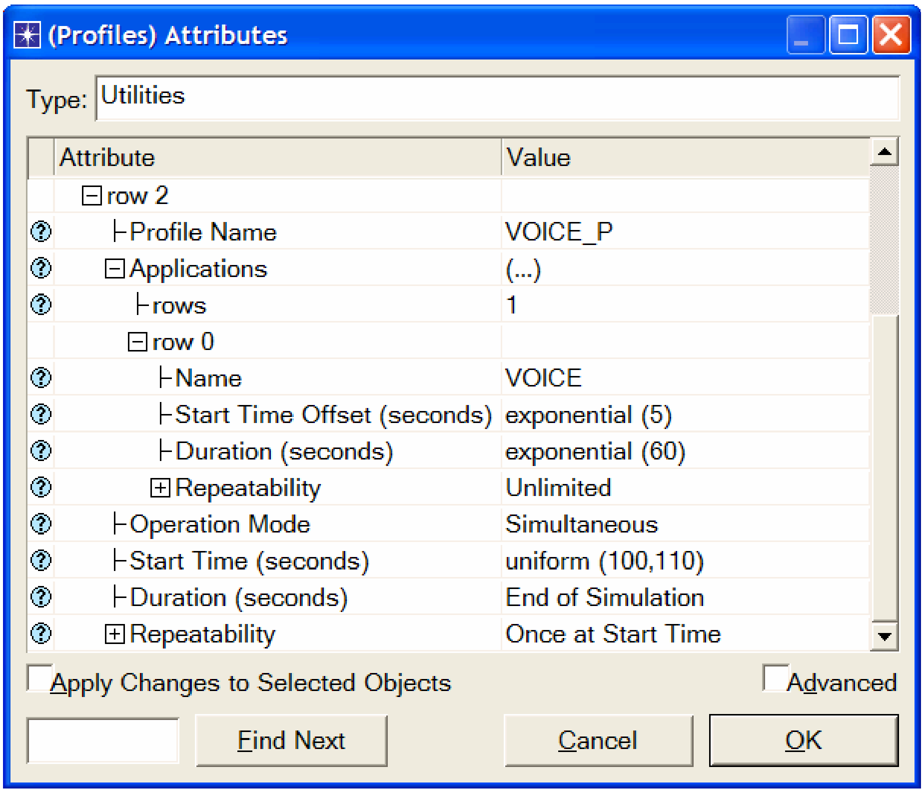
   i. Name and set the attributes of **row 0** as shown:



ii. Name and set the attributes of row 1 as shown:

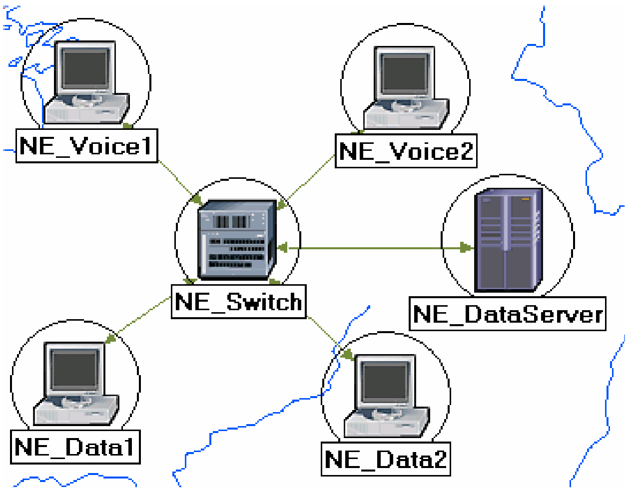


iii. Name and set the attributes of row 2 as shown. (Note: To set the **Duration** to **exponential(60)**, you will need to assign "**Not Used**" to the "**Special Value**")
⇒ Close the *Object Palette* dialog box.



5.4.3.3. *Configure the NorthEast Subnet:*

1. Double-click on the **NorthEast** subnet node. You get an empty workspace, indicating that the subnet contains no objects.
2. Open the object palette  and make sure that **atm_advanced** is selected from the pull-down menu on the object palette ...
3. Add the following items to the subnet workspace one **atm8crossconn_adv** switch one **atm_uni_server_adv**, four **atm_uni_client_adv**, and connect them with bidirectional **atm_adv** links ⇒ Close the palette ⇒ Rename the objects as shown.



Hint: To edit the attributes of multiple of multiple nodes in the single operation, select all nodes simultaneously using shift and left-click, then **Edit Attributes** of one of the nodes, and select **Apply Changes to Selected Objects**.

4. Change the **data rate** attribute for all links to **DS1**.
5. For both **NE_Voice1** and **NE_Voice2**, set the following attributes:
   i. Set **ATM Application Parameters** to **CBR** only.

ii. Expand the **ATM Parameters** hierarchy ⇒ Set **Queue Configuration** to **CBR** only.

iii. Expand the **Application: Supported Profiles** hierarchy ⇒ Set **rows** to **1** ⇒ Expand the **row 0** hierarchy ⇒ Set **Profile Name** to **VOICE_P**.

iv. **Application: Supported Services** ⇒ **Edit** its value ⇒ Set **rows** to **1** ⇒ Set **Name** of the added row to **VOICE** ⇒ Click **OK**.

v. Expand the **Application: Transport Protocol** hierarchy ⇒ **Voice Transport = AAL2**.

Client Address is the Transport Adaptation Layer (TPAL) address of the node. This value must be unique for each node. The **TPAL model** suite presents a basic, uniform interface between applications and transport layer models. All interactions with a remote application through TPAL are organized into session. A session is a single conversation between two applications through a transport protocol.

6. For **NE_Voice1**, select **Edit Attributes** ⇒ Edit the value of the **Client Address** attribute and write down **NE_Voice1**.
7. For **NE_Voice2**, select **Edit Attributes** ⇒ Edit the value of the **Client Address** attribute and write down **NE_Voice2**.
8. Configure the **NE_DataServer** as follows:

i. **Application: Supported Services** ⇒ **Edit** its value ⇒ Set **rows** to **2** ⇒ Set **Name** of the added rows to: **EMAIL** and **FTP** ⇒ Click **OK**.

ii. Expand the **Application: Transport Protocol Specification** hierarchy ⇒ **Voice Transport = AAL2**.

iii. Edit the value of the **Server Address** attribute and write down **NE DataServer**.

The **queue configuration** specifies a one-to-one mapping between output port queues and the QoS that they support. A specific queue may be configured to support a specific QoS.

9. For both **NE_Data1** and **NE_Data2**, set the following attributes:

i. Expand the **ATM Parameters** hierarchy ⇒ Set **Queue Configuration** to **UBR**.

ii. Expand the **Application: Supported Profiles** hierarchy ⇒ Set **rows** to **2** ⇒ Set **Profile Name** to **FTP_P** (for **row 0**) and to **EMAIL_P** (for **row 1**).

10. For **NE_Data1**, select **Edit Attributes** ⇒ Edit the value of the **Client Address** attribute and write down **NE_Data1**.
11. For **NE_Data2** select **Edit Attributes** ⇒ Edit the value of the **Client Address** attribute and write down **NE_Data2**.
12. Save your project.

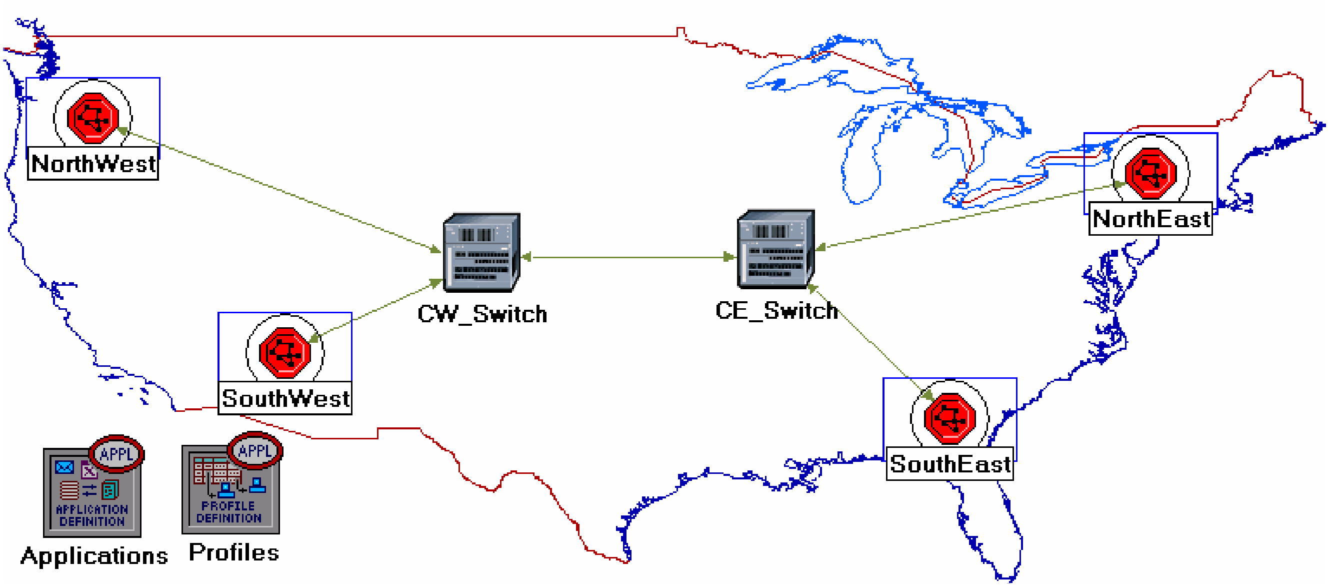
5.4.3.4. Add Remaining Subnets:

1. Now you completed the configuration of the NorthEast subnet. To go back to the project space, click the **Go to the higher level**  button.

The subnets of the other regions should be similar to the *NorthEast* one except for the names and **server address**es.

2. Make three copies of the subnet we just created.
3. Rename (right-click on the node ⇒ Set **Name**) the subnets and connect them to the switches with bidirectional **atm_adv** links as shown. (*Note*: You will be asked

to pick the node inside the subnet to be connected to the link. Make sure to choose the "switch" inside each subnet to be connected.)

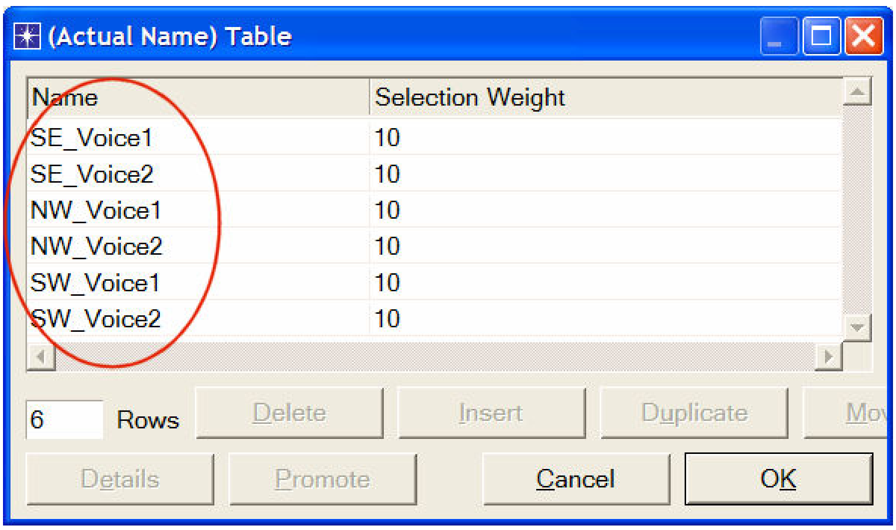


4. Change the **data rate** for all links to **DS1**.
5. Select and double-click each of the new subnets (total four subnets) and change the **names**, **server address**, and **server address** of the nodes inside these subnets as appropriate (e.g., replace NE with SW for the *SouthWest* subnet).

Hint: To do step 6, you can right-click on any voice station and choice **Edit Similar Nodes.** This brings up a table in which each node occupies one row and attributes are shown in the columns. Follow the same procedure with similar steps in this lab.

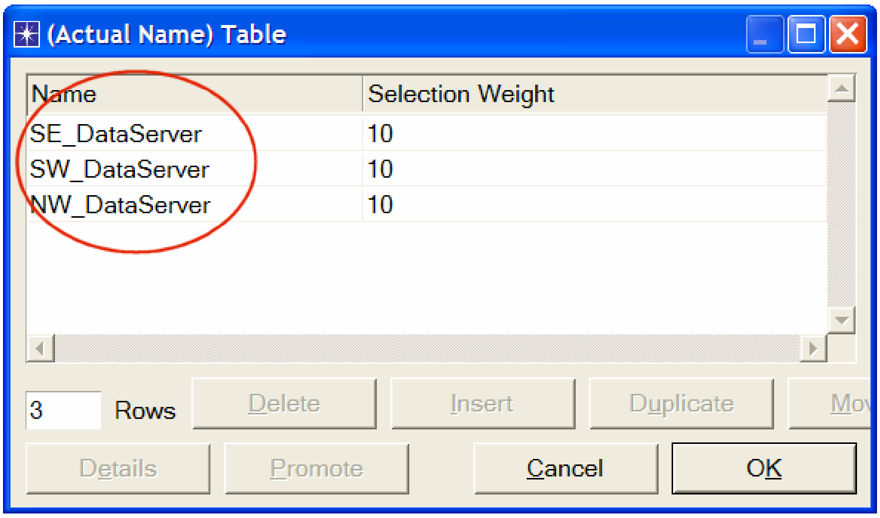
6. For all **voice** stations in all subnets (total of eight stations), edit the value of the **Application: Destination Preferences** attribute as follows:

   i. Set **rows** to **1** ⇒ Set **Symbolic Name** to **Voice Destination** ⇒ Click on (…) under the **Actual Name** column ⇒ Set **rows** to **6** ⇒ For each row choose a voice station that is not in the current subnet. The following figure shows the actual names for one of the **voice** stations in the *NorthEast* subnet:



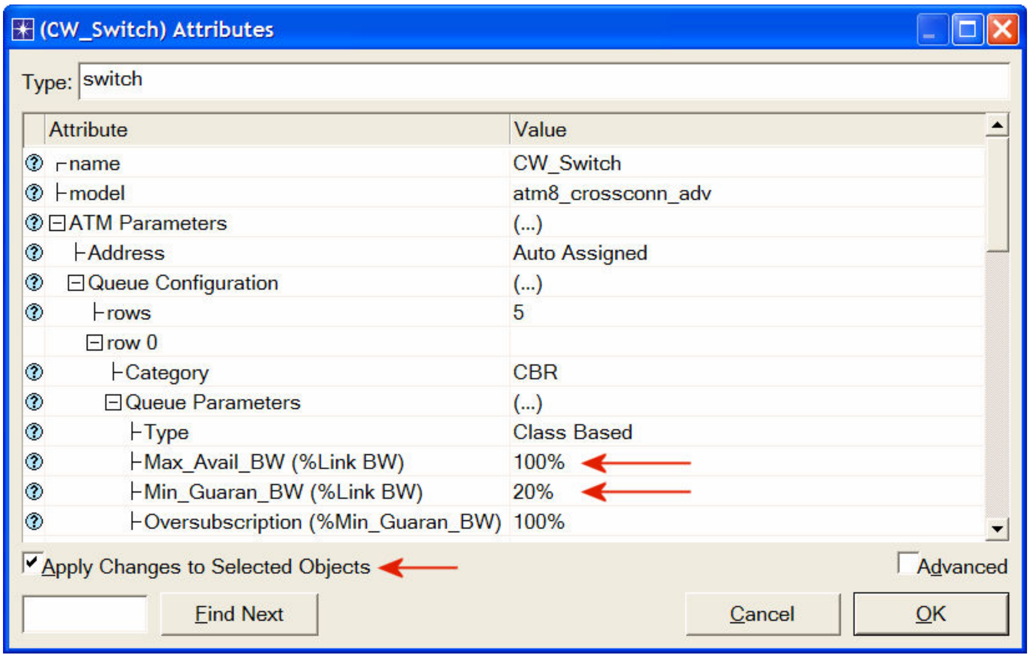
7. For all **data** stations in all subnets (total of eight stations), configure the **Application: Destination Preferences** attribute as follows:

   ii. Set **rows** to **2** ⇒ Set **Symbolic Name** to **FTP Server** for the one row and **Email Server** for the other row ⇒ For each symbolic name (i.e., **FTP Server** and Email Server), click on (.) under the **Actual Name** column ⇒ Set **rows** to **3** ⇒ For each row choose a data server that is not in the current subnet The following figure shows the actual names for one of the **data** stations in the *NorthEast* subnet:



Hint: To do step 8 in a single operation, you can use the right-click menu on any switch to **Select Similar Nodes**, then **Edit Attributes**, and check **Apply Changes to Selected Objects**. This feature does work, even across objects in different subnets.

8. For all **switches** in the network (total of six switches) configure the **Max_Avail_BW** of the CBR queue to be 100%, as shown bellow, and the **Min_Guaran_BW** to be 20%.



Max_Avail_BW is the maximum bandwidth allocated to this queue. Calls will be admitted into this queue only if they are within the maximum available bandwidth requirement.

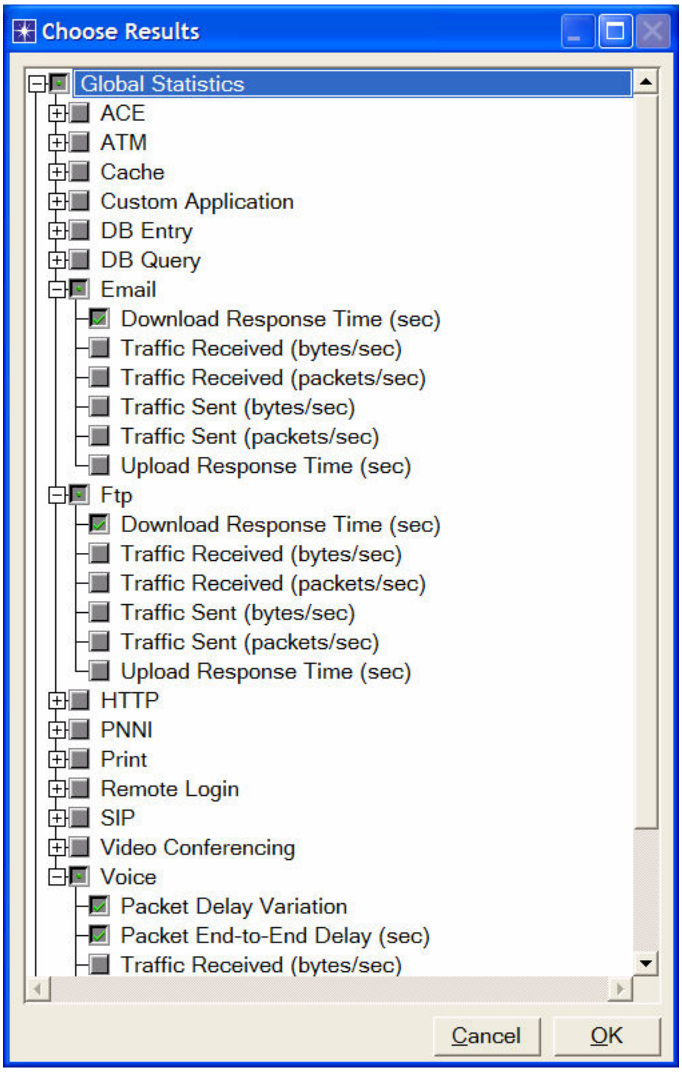
9. Save your project.

5.4.4. Choose the Statistics

To test the performance of the applications defined in the network, 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, choose the following statistics:



3. Click **OK**.

5.4.5. Configure the Simulation

Here we need to configure the duration of the simulation:

1. Click on the **Configure/Run Simulation** button: .
2. Set the duration to be **10.0 minutes**.
3. Click **OK**. We will be running the simulation later.

5.4.6. Duplicate the Scenario

In the network we just created, we used the CBR service class for the Voice application and the UBR service class for the FTP and Email applications. To analyze the effect of such different classes of services, we will create another scenario that is similar to the **CBR_UBR** scenario we just created but it uses only one class of service, UBR, for all applications. In addition, to test the effect of the ATM adaptation layer, in the new scenario we will use AAL5 for the Voice application rather than AAL2.

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

2. For all **voice** stations in all subnets, reconfigure them as follows. (Check the note below for a faster way to carry out this step.)

   i. Set **ATM Application Parameters** to **UBR only**.

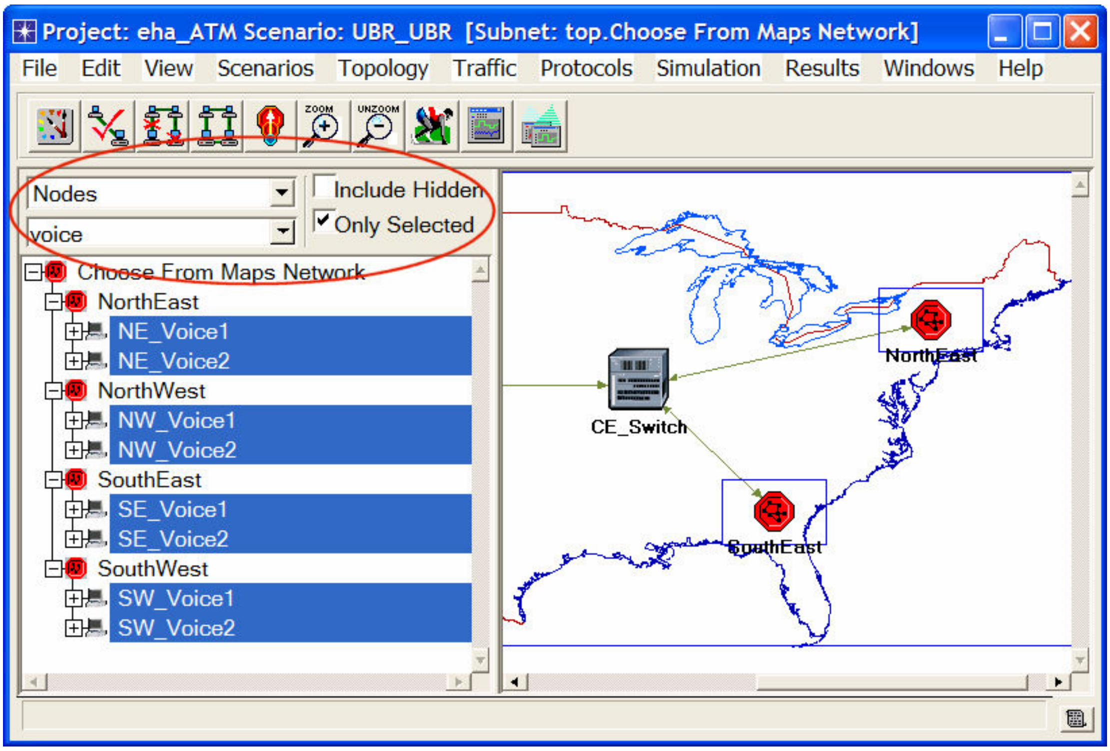
   ii. ATM Parameters ⇒ Set **Queue Configuration** to **UBR**.

   iii. **Application: Transport Protocol** ⇒ Set **Voice Transport** to **AAL5**.

3. Save your project.

   Note: One easy way to carry out step 2 above is through the network browser as:

   - Select **Show Network Browser** from the **View** menu.
   - Select **Nodes** from the drop-down menu, and check the **Only Selected** check box as shown in the following figure.
   - Write **voice** in the find field and click **Enter.**
   - In the network browser you should see a list of all **voice** stations selected.
   - Right-click on any of the **voice** stations in the list, select **Edit Attributes,** and check **Apply Changes to Selected Objects**.
   - Carry out the configuration changes in step 2 above.
   - To hide the network browser, deselect **Show Network Browser** from the **View** menu.

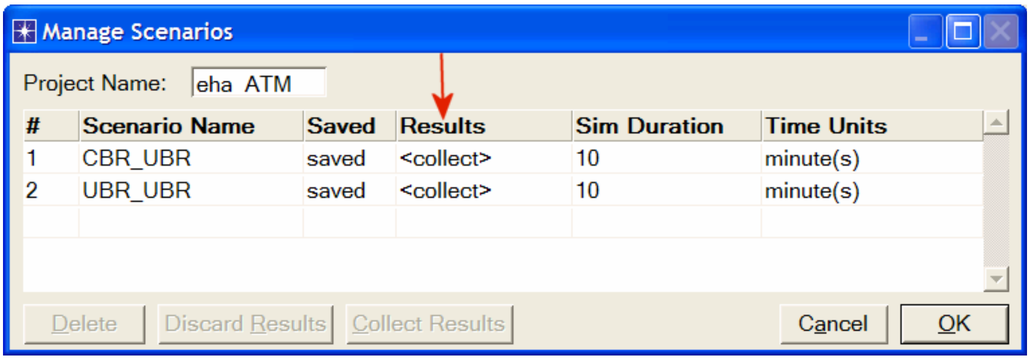


5.4.7. Run the Simulation

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.

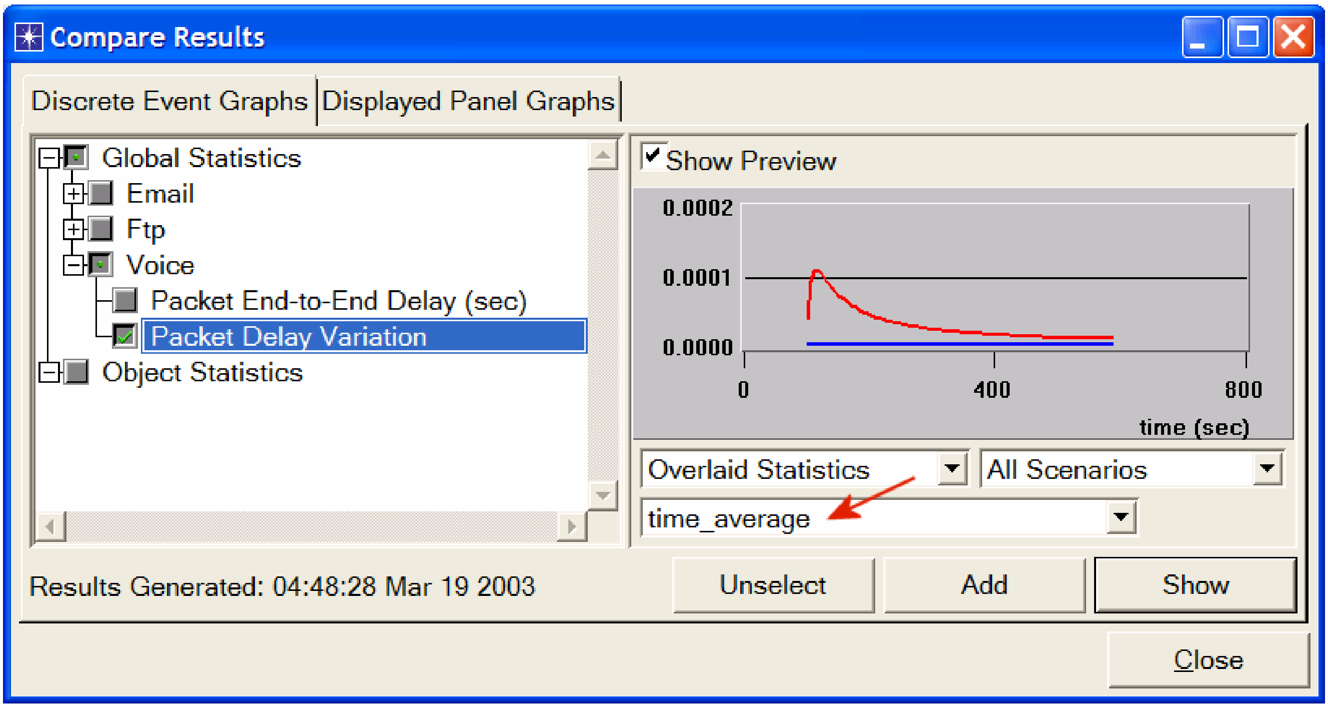


3. Click **OK** to run the two simulations. Depending on the speed of your processor, this may take several minutes to complete.
4. After the two simulation runs complete, one for each scenario, click **Close**.
5. Save your project.

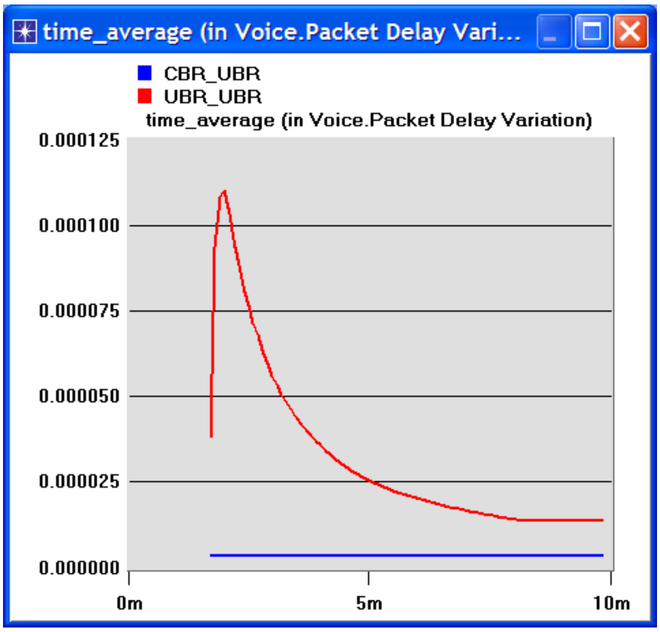
5.4.8. View the Results

To view and analyze the results:

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 the voice **Packet Delay Variation** statistic and click **Show**. The resulting graph should resemble the one below. (Note: Result may vary slightly due to different node placement.)



5.5. *Further readings*

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

5.6. *Exercises*

1) Analyze the result we obtained regarding the voice **Packet Delay Variation** time. Obtain the graphs that compare the **Voice packet end-to-end delay** the **Email download response time,** and the **FTP download response time** for both scenarios. Comment on the results.

2) Create another scenario as a duplicate of the **CBR_UBR** scenario Name the new scenario **Q2_CBR_ABR**. In the new scenario you should use the **ABR** class of service for data, i.e., the FTP and Email applications in the data stations. Compare the performance of the **CBR_ABR** scenario with that of the **CBR_UBR** scenario.

   Hints:

   - To set **ABR** class of service to a node, assign **ABR Only** to its **ATM Application Parameters** attribute and **ABR only (Per VC Queue)** to its **Queue Configuration** (one of the **ATM Parameters).**
   - For all **switches** in the network (total of 6 switches), configure the **Max_Avail_BW** of the **ABR** queue to be 100% and the **Min_Guaran_BW** to be 20%.

3) Edit the FTP application defined in the **Applications** node so that its **File Size** is twice the current size (i.e., make it 100000 bytes instead of 50000 bytes). Edit the **EMAIL** application defined in the **Applications** node so that its **File Size** is five times the current size (i.e., make it 10000 bytes instead of 2000 bytes). Study how this affects the voice application performance in both the **CBR_UBR** and **UBR_UBR** scenarios. (*Hint*: to answer this exercise, you might need to create duplicates of the **CBR_UBR** and **UBR_UBR** scenarios. Name the new scenarios **Q3_CBR_UBR** and **Q3_UBR_UBR** respectively).

5.7. *Lab Report*

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

6. Laboratory - RIP: Routing Information Protocol (A Routing Protocol Based on the Distance-Vector Algorithm)

6.1. *Objective*

The objective of this lab is to configure and analyze the performance of the Routing Information Protocol (RIP) model.

6.2. *Overview*

A router in the network needs to be able to look at a packet's destination address and then determines which one of the output ports is the best choice to get the packet to that address. The router makes this decision by consulting a forwarding table. The fundamental problem of routing is: How do routers acquire the information in their forwarding tables?

Routing algorithms are required to build the routing tables and hence forwarding tables. The basic problem of routing is to find the lowest-cost path between any two nodes, where the cost of a path equals the sum of the costs of all the edges that make up the path. Routing is achieved in most practical networks by running routing protocols among the nodes. The protocols provide a distributed, dynamic way to solve the problem of finding the lowest-cost path in the presence of link and node failures and changing edge costs.

One of the main classes of routing algorithms is the distance-vector algorithm. Each node constructs a vector containing the distances (costs) to all other nodes and distributes that vector to its immediate neighbors RIP is the canonical example of a routing protocol built on the distance-vector algorithm. Routers running RIP send their advertisements regularly (e.g., every 30 seconds). A router also sends an update message whenever a triggered update from another router causes it to change its routing table.

The Internet Control Message Protocol (ICMP) can be utilized to analyze the performance of the created routes. It can be used to model traffic between routers without the need of running applications in an end node.

In this lab you will set up a network that utilizes RIP as its routing protocol. You will analyze the routing tables generated in the routers, and you will observe how RIP is affected by link failures. You will also utilize the ICMP to create echo reply messages (i.e., ping) to analyze the created routes.

6.3. *Prelab Activities*

- Read sections 4.1.5, 4.1.7, and 4.2.2 from ***"Computer Networks: A Systems Approach",*** 4th ***Edition.***

Go to www.net-seal.net/animations.php and play the following animations:

- The Address Resolution Protocol (ARP). Example1, Example2, Example3.
- ARP with Multiple Networks.
- Routing and Forwarding.

6.4. *Procedure*

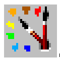
6.4.1. Create a New Project

1. Start **OPNET IT Guru Academic Edition** ⇒ Choose **New** from the **File** menu.

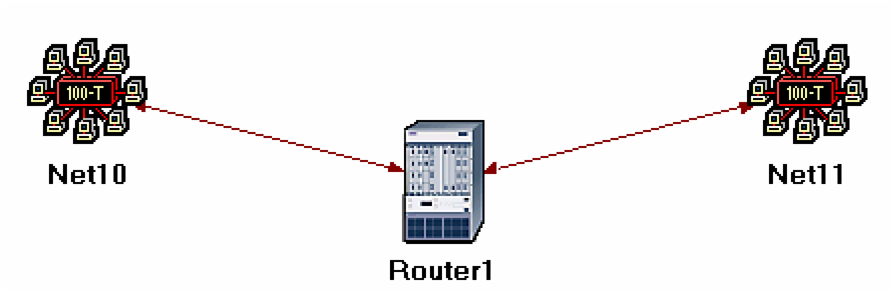
2. Select **Project** and Click **OK** ⇒ Name the project **<your initials>_RIP**, and the scenario **NO_Failure** ⇒ Click **OK**.
3. In the *Startup Wizard: Initial Topology* dialog box, make sure that **Create Empty Scenario** is selected ⇒ Click **Next** ⇒ Select **Campus** from the *Network Scale* list ⇒ Click **Next** three times ⇒ Click **OK**.

6.4.2. Create and Configure the Network

6.4.2.1. Initialize 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: one **ethernet4_slip8_gtwy** router 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 **100BaseT** links to connect the objects you just added as in the following figure. Also, rename the objects as shown (right-click on the node ⇒ Set **Name**).
4. Close the *Object Palette* dialog box.
5. Save your project.

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. The Routing Information Protocol (RIP) or the Open Shortest Path First (OSPF) protocol may be used to dynamically and automatically create the gateway's routing tables and select routes in an adaptive manner.



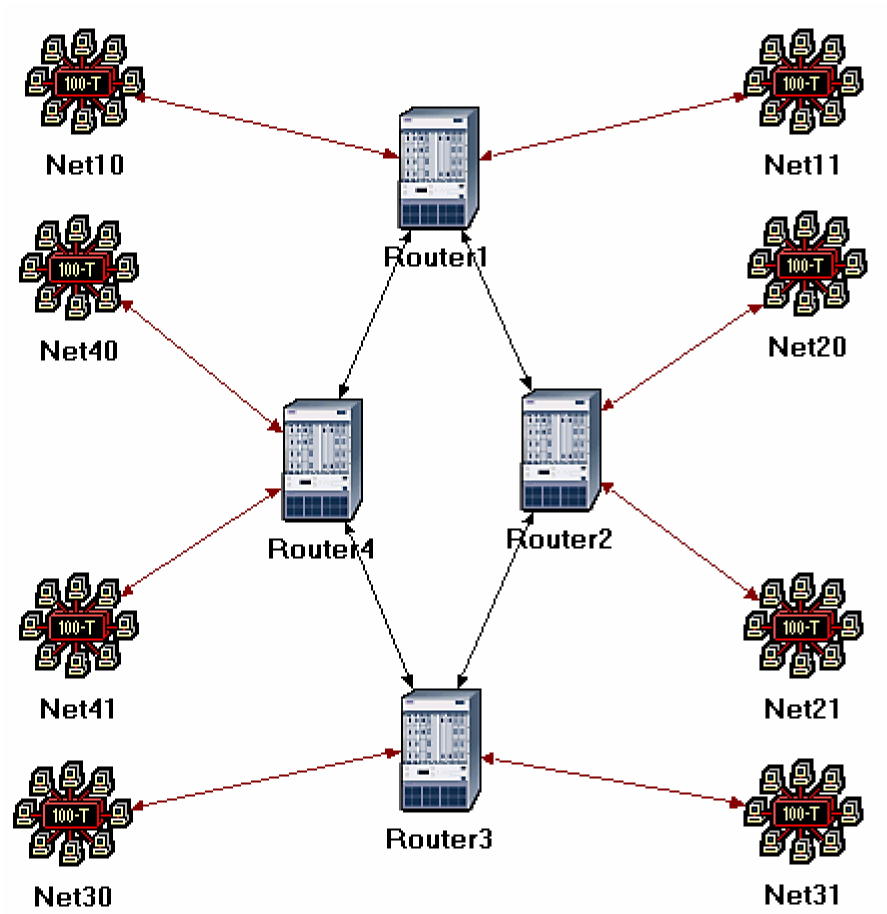
6.4.2.2. Configure the Router:

1. Right-click on **Router1** ⇒ **Edit Attributes** ⇒ Expand the **IP Routing Parameters** hierarchy and set the following:
   i. **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*.
2. Click **OK** and then save your project.

6.4.2.3. Add the Remaining LANs:

1. Highlight or select simultaneously (using shift and left-click) all five objects that you currently have in the project workspace (one router, two LANs, and two links). You can click-and-drag a box around the objects to do this.

2. Press **Ctrl+C** to copy the selected objects and then press **Ctrl+V** to paste them.
3. Repeat step 2 three times to generate three new copies of the objects and arrange them in a way similar to the following figure. Rename all objects as shown.
4. Connect routers, as shown, using **PPP_DS3** links.



The **PPP_DS3** link has a data rate of 44.736 Mbps.

6.4.3. Choose the Statistics

To test the performance of the RIP protocol, we will collect the following statistics:

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, check the following statistics:
   a. **Global Statistics ⇒ RIP ⇒ Traffic Sent (bits/sec).**
   b. **Global Statistics ⇒ RIP ⇒ Traffic Received (bits/sec)**.
   c. **Nodes Statistics ⇒ Route Table ⇒ Total Number of Updates.**
3. Click **OK** and then save your project.

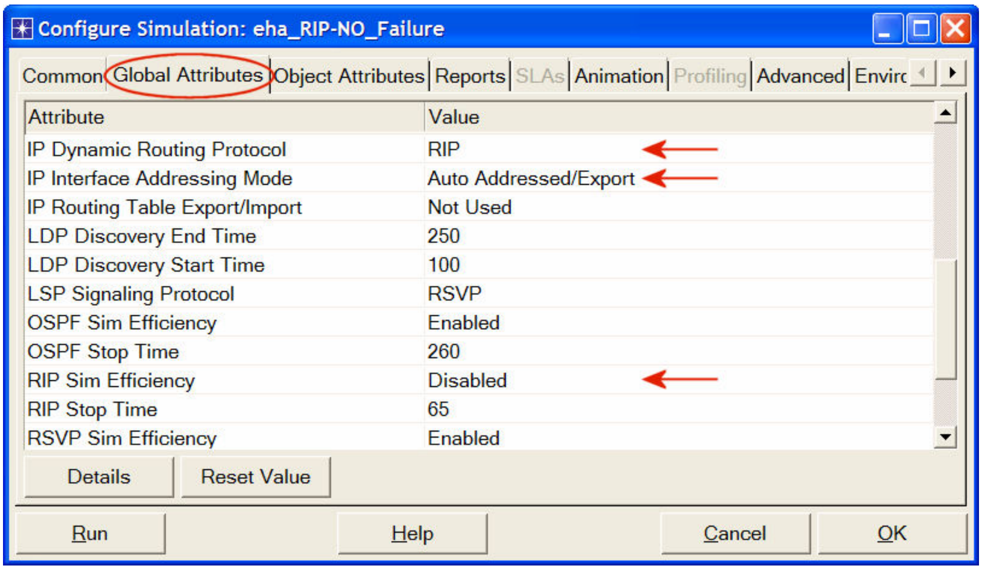
RIP traffic is the total amount of RIP update traffic (in bits) sent/received per second by all the nodes using RIP as the routing protocol in the IP interfaces in the node.

Total Number of Updates is the number of times the routing table at this node gets updated (e.g., due to a new route addition, an existing route deletion, and/or a next hop update).

6.4.4. 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 be **10.0 minutes.**
3. Click on the **Global Attributes** tab and change the following attributes:
   a. **IP Dynamic Routing Protocol = RIP.** This sets the RIP protocol to be the routing protocol of all routers in the network.
   b. **IP Interface Addressing Mode = Auto Addressed/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 (as we will see in the second scenario).
4. Click **OK** and then save the project.



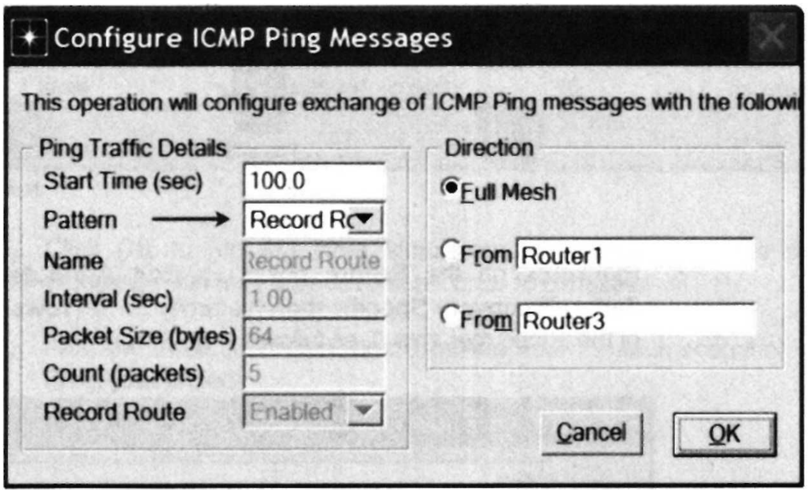
Auto Addressed means that all IP interfaces are assigned IP addresses automatically during simulations. The class of address (e.g., A, B, or C) is determined based on the number of hosts in the designed network. Subnet masks assigned to these interfaces are the default subnet masks for that class.

Export causes the auto-assigned IP interface to a file (name of the file is <net_name> ip_address.gdf and gets saved in the primary model directory).

6.4.5. The Ping Scenario

In this scenario we will utilize the ping model to print the list of traversed nodes while the ICMP request message is sent to the destination and the ICMP response is received from the destination. Traversed routes are logged in the simulation log file …

1. Select **Duplicate Scenario** from the **Scenarios** menu and name it **ICMP_Ping** ⇒ Click **OK.**
2. Select both **Router1** and **Router3** simultaneously (click on both of them while holding the **Shift** key) ⇒ Select the **Protocols** menu ⇒ **IP** ⇒ **Demands** ⇒ **Configure Ping Traffic on Selected Nodes**.
3. Change the Pattern attribute to Record Route as shown ⇒ Click **OK.**



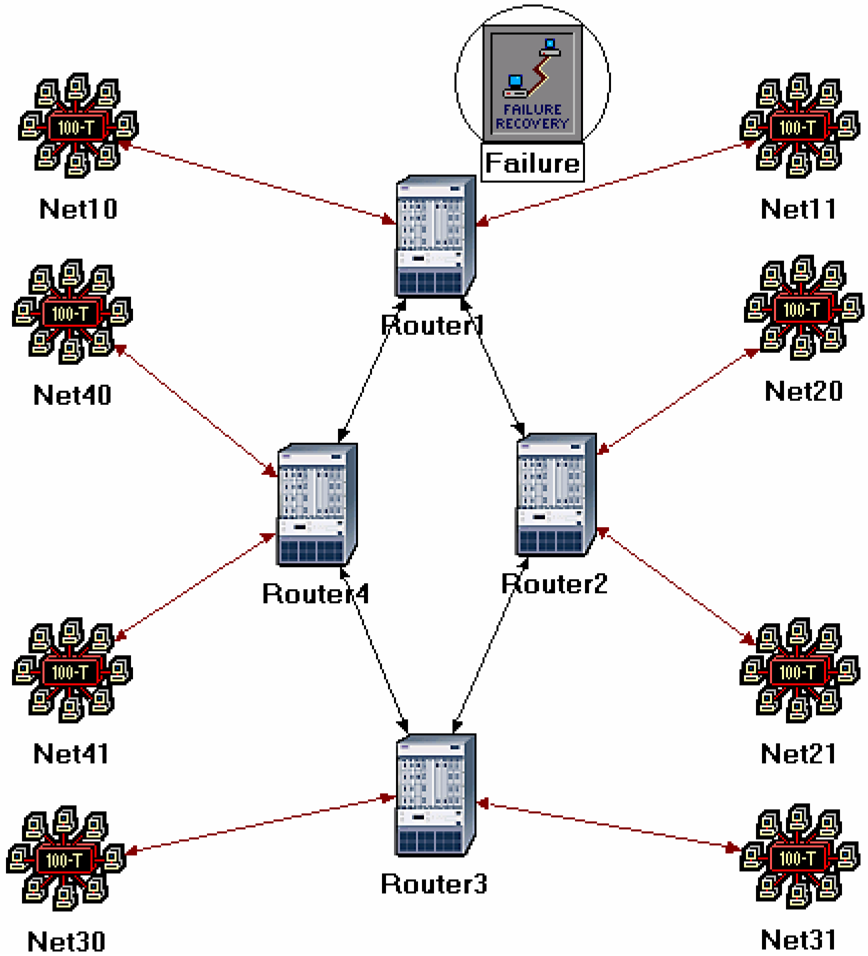
Notice that a *Ping Parameter* node will be added to the project space. In addition the ping demand is created between *Rotuer1* and *Router3* as a dotted line.

6.4.6. The Failure Scenario

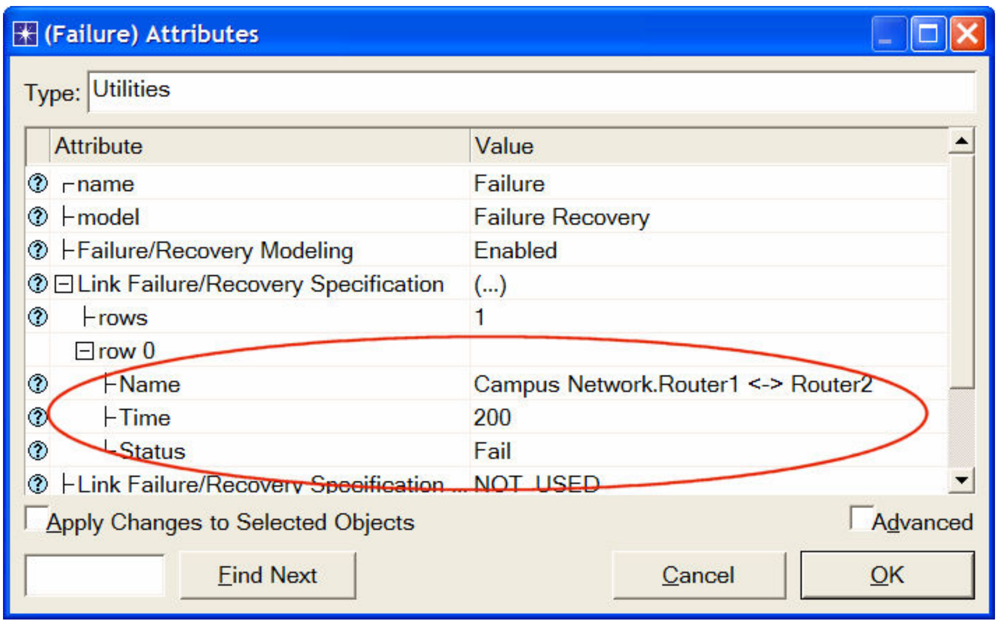
The routers in the network we created will build their routing tables with no need to update these tables further because we didn't simulate any node or link failures. In this scenario we will simulate failures so that we can compare the behavior of the routers in both cases.

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

2. Open *Object Palette* by clicking . Select the **Utilities** palette from the drop-down menu ⇒ Add a **Failure Recovery** object to your workspace and name it **Failure** as shown ⇒ Close the *Object Palette* dialog box.



3. Right-click on the **Failure** object ⇒ **Edit Attributes** ⇒ Expand the **Link Failure/Recovery Specification** hierarchy ⇒ Set **rows** to **1** ⇒ Set the attributes of the added row, **row 0**, as follows:



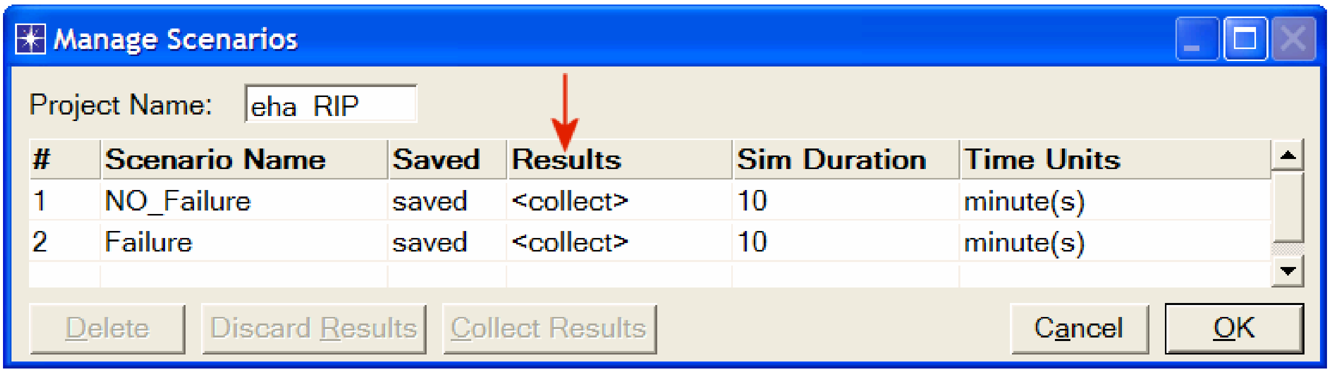
4. This will "fail" the link between **Router1** and **Router2** 200 seconds into the simulation.

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

6.4.7. 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 the three scenarios. Compare to the following figure.

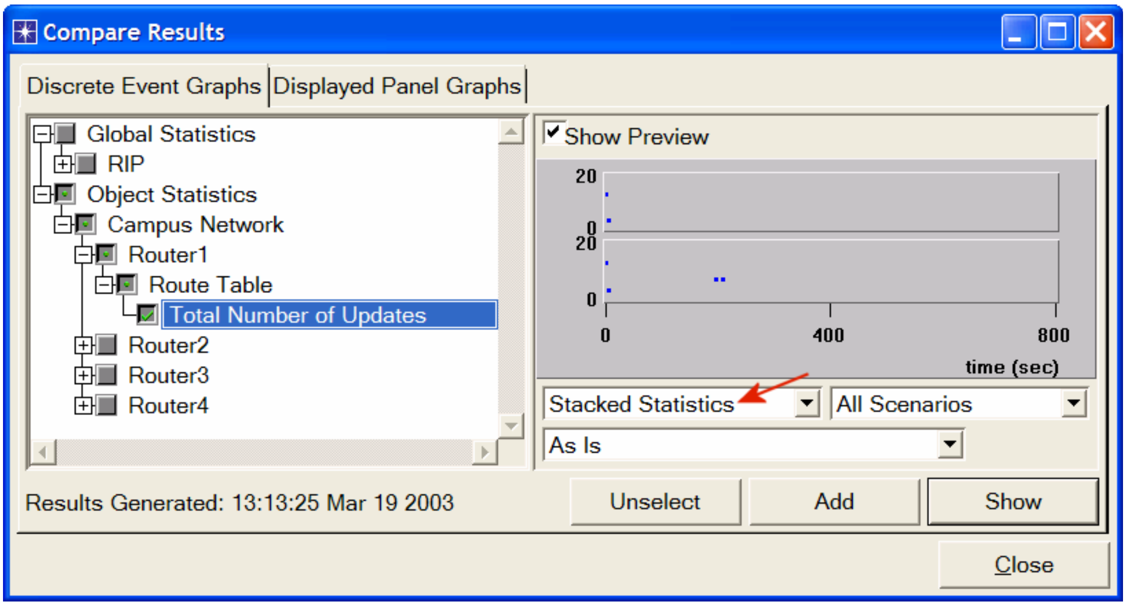


3. Click **OK** to run the three simulations. Depending on the speed of your processor, this may take several seconds to complete.
4. After the three simulation runs complete, one for each scenario, click **Close** ⇒ Save your project.

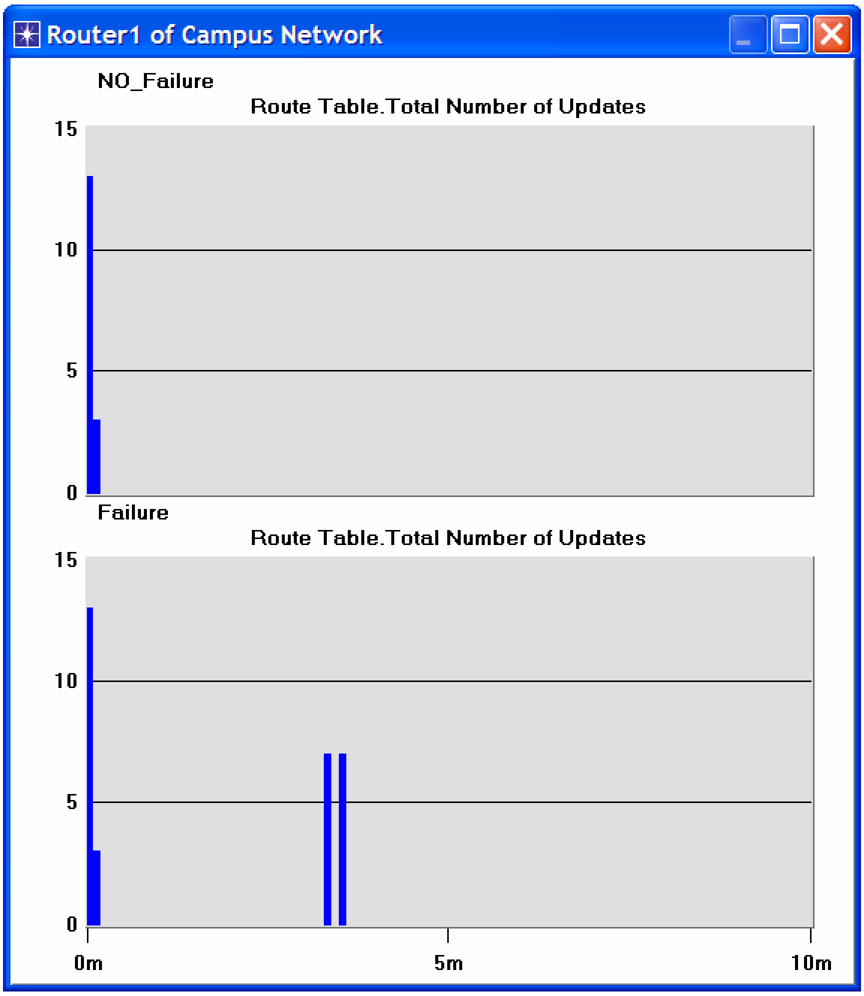
6.4.8. View the Results

6.4.8.1. Compare the Number of Updates:

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 to **Stacked Statistics** and **Select Scenarios** as shown.



3. Select the **Total Number of Updates** statistic for **Router1** and click **Show** ⇒ Select the **NO_Failure** and **Failure** scenarios in the **Select Scenarios** dialog box.
4. You should get two graphs, one for each scenario. Right-click on each graph and select **Draw Style** ⇒ **Bar**.
5. The resulting graphs should resemble the following (you can zoom in on the graphs by clicking-and-dragging a box over the region of interest):

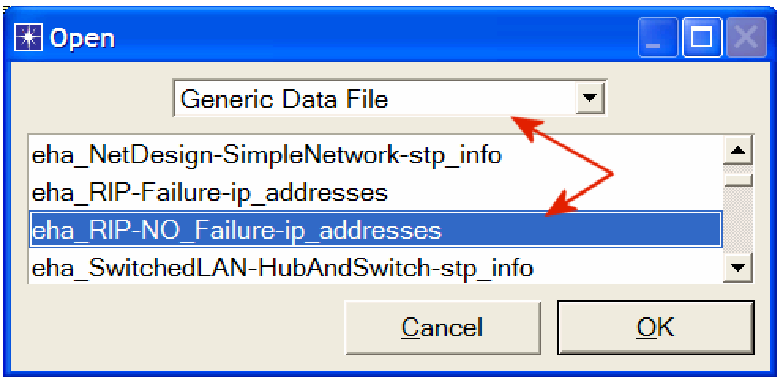


6.4.8.2. *Obtain the IP Addresses of the Interface:*

Before checking the contents of the routing tables, we need to determine the IP address information for all interfaces in the current network. 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. 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.

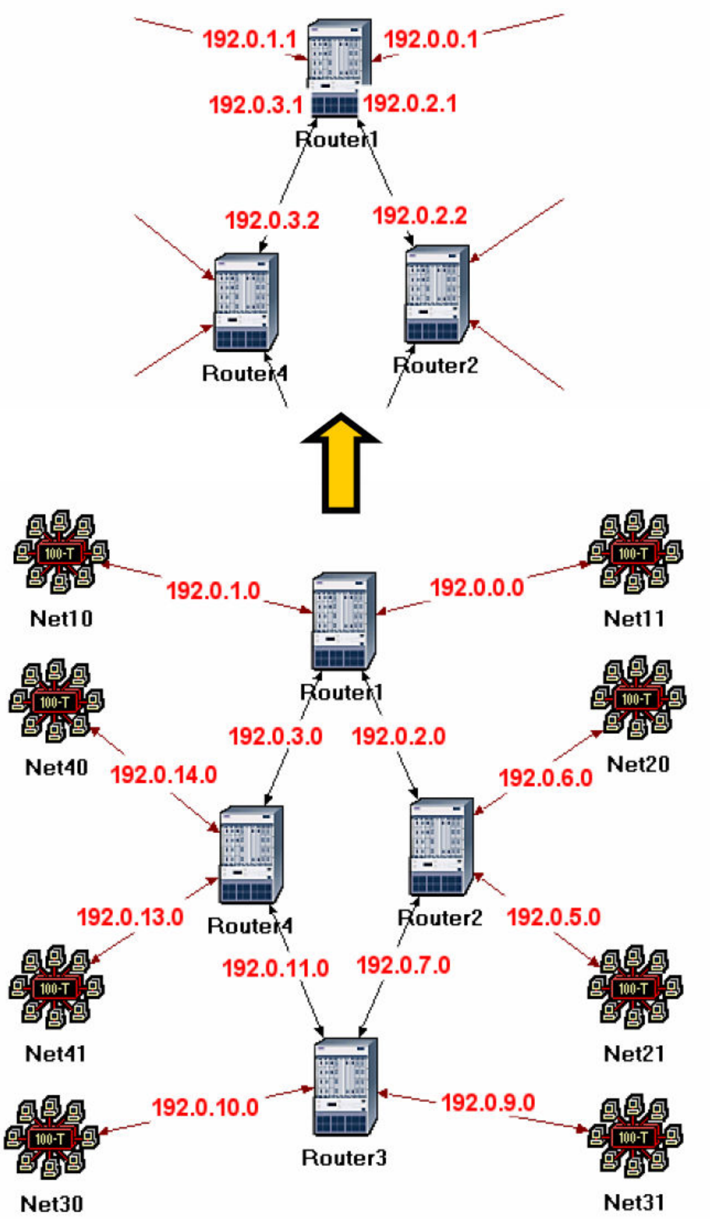
2. From the **File** menu choose **Open** ⇒ From the drop-down menu choose **Generic Data File** ⇒ Select the **<your initials>_RIP-NO_Failure-ip_addresses** file (the other file created from the **Failure** scenario should contain the same information) ⇒ Click **OK.**



3. The following is a part of the **gdf** file content. It shows the IP addresses assigned to the interfaces of **Router1** in our network. For example the interface of **Router1** that is connected to **Net11** has the IP address 192.0.0.1 (Note: Your result may vary due to different nodes placement.) The **Subnet Mask** associated with that interface indicates that the address of the sub-network, to which the interface is connected, is 192.0.0.0 (i.e., the logical AND of the interface IP address and the subnet mask).

```
Node Name: Campus Network.Router1
 Iface Name           Iface Index    IP Address       Subnet Mask      Connected Link
 ----------           -----------    -------------    -------------    ----------------
 IF0                      0             192.0.0.1        255.255.255.0    Campus Network.Net11 <-> Router1
 IF1                      1             192.0.1.1        255.255.255.0    Campus Network.Net10 <-> Router1
 IF10                     10            192.0.2.1        255.255.255.0    Campus Network.Router1 <-> Router2
 IF11                     11            192.0.3.1        255.255.255.0    Campus Network.Router4 <-> Router1
 Loopback                 12            192.0.4.1        255.255.255.0    Not connected to any link.
```

4. Print out the layout of the network you implemented in this lab. On this layout, from the information included in the **gdf** file, write down the IP addresses associated with **Router1** as well as the addresses assigned to each sub-network as shown in the following two figures (Note: Your IP addresses may vary due to different nodes placement.)



6.4.8.3. *Getting the Ping Report:*

1. To check the content of the ping report for **Router1**:

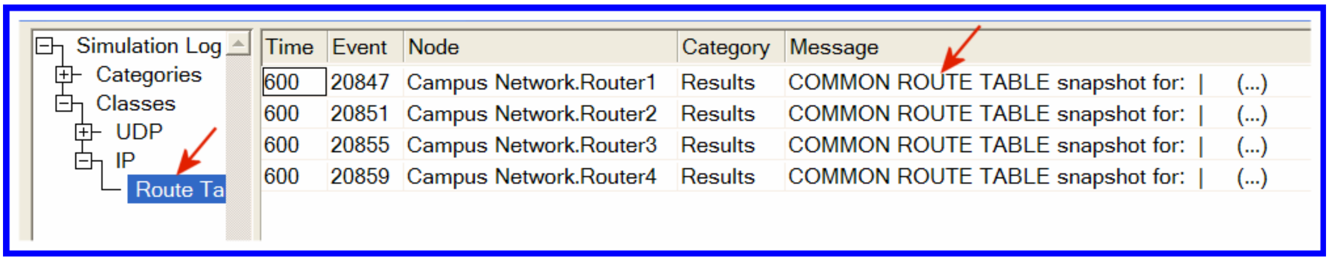
   i. Go to the **ICMP_Ping** scenario ⇒ Go to the **Results** menu ⇒ Open **Simulation Log** ⇒ Click on the field **PING REPORT** for "**Campus Network Router1**". The report should resemble the following one:

```
PING REPORT for "Campus Network.Router1" (192.0.4.1)

DETAILS:
  Received  ICMP echo reply packet for a
  request packet sent to the following node:

    IP Address: 192.0.4.1
    Node Name : Campus Network.Router1

PERFORMANCE:
  Based on the first ICMP echo request packet
  (i.e., a "ping" packet) sent to the above
  node, the following metrics were computed:

    1. Response Time: 0.00028 seconds

    2. List of traversed IP interfaces:

       IP Address         Hop Delay       Node Name
       ----------         ---------       ---------
        192.0.7.2         0.00000       Campus Network.Router3
        192.0.2.2         0.00005       Campus Network.Router2
        192.0.4.1         0.00007       Campus Network.Router1
        192.0.2.1         0.00002       Campus Network.Router1
        192.0.7.1         0.00005       Campus Network.Router2
        192.0.7.2         0.00006       Campus Network.Router3

  Note that the IP addresses shown above represent
  the address of the output interface on which the
  IP datagram was routed from the corresponding
  nodes to the next node enroute to its destination
  and back.
```

6.4.8.4. *Compare the Routing Tables Content:*

1. To check the content of the routing tables in **Router1** for the **Failure** and **NO_Failure** scenarios:

   i. Go to the **Results** menu. ⇒ Open **Simulation Log** ⇒ Expand the hierarchy on the left as shown below. ⇒ Click on the field **COMMON ROUTE TABLE**.



2. Carry out the previous step for the Failure and **NO_Failure** scenarios. The following are partial contents of **Router1**'s routing table for both scenarios (Note: Your results may vary due to different nodes placement):

Routing table of **Router1** (**NO Failure** scenario):

```
  Router name: Campus Network.Router1
      at time: 600.00 seconds

ROUTE TABLE contents:

   Dest. Address      Subnet Mask        Next Hop         Interface Name     Metric       Protocol
  ---------------   ---------------   ---------------   ---------------     ------       --------

  192.0.0.0         255.255.255.0     192.0.0.1         IF0                 0             Direct
  192.0.1.0         255.255.255.0     192.0.1.1         IF1                 0             Direct
  192.0.2.0         255.255.255.0     192.0.2.1         IF10                0             Direct
  192.0.3.0         255.255.255.0     192.0.3.1         IF11                0             Direct
  192.0.4.0         255.255.255.0     192.0.4.1         Loopback            0             Direct
  192.0.5.0         255.255.255.0     192.0.2.2         IF10                1             RIP
  192.0.6.0         255.255.255.0     192.0.2.2         IF10                1             RIP
  192.0.7.0         255.255.255.0     192.0.2.2         IF10                1             RIP
  192.0.8.0         255.255.255.0     192.0.2.2         IF10                1             RIP
  192.0.11.0        255.255.255.0     192.0.3.2         IF11                1             RIP
  192.0.13.0        255.255.255.0     192.0.3.2         IF11                1             RIP
  192.0.14.0        255.255.255.0     192.0.3.2         IF11                1             RIP
  192.0.15.0        255.255.255.0     192.0.3.2         IF11                1             RIP
  192.0.9.0         255.255.255.0     192.0.2.2         IF10                2             RIP
  192.0.10.0        255.255.255.0     192.0.2.2         IF10                2             RIP
  192.0.12.0        255.255.255.0     192.0.2.2         IF10                2             RIP
```

Loopback interface allows a client and a server on the same host to communicate with each other using TCP/IP.

Routing table of **Router1** (**Failure** scenario):

```
  Router name: Campus Network.Router1
      at time: 600.00 seconds

ROUTE TABLE contents:

   Dest. Address      Subnet Mask        Next Hop         Interface Name     Metric       Protocol
  ---------------   ---------------   ---------------   ---------------     ------       --------

  192.0.0.0         255.255.255.0     192.0.0.1         IF0                 0             Direct
  192.0.1.0         255.255.255.0     192.0.1.1         IF1                 0             Direct
  192.0.2.0         255.255.255.0     192.0.2.1         IF10                0             Direct
  192.0.3.0         255.255.255.0     192.0.3.1         IF11                0             Direct
  192.0.4.0         255.255.255.0     192.0.4.1         Loopback            0             Direct
  192.0.11.0        255.255.255.0     192.0.3.2         IF11                1             RIP
  192.0.13.0        255.255.255.0     192.0.3.2         IF11                1             RIP
  192.0.14.0        255.255.255.0     192.0.3.2         IF11                1             RIP
  192.0.15.0        255.255.255.0     192.0.3.2         IF11                1             RIP
  192.0.5.0         255.255.255.0     192.0.3.2         IF11                3             RIP
  192.0.6.0         255.255.255.0     192.0.3.2         IF11                3             RIP
  192.0.7.0         255.255.255.0     192.0.3.2         IF11                2             RIP
  192.0.8.0         255.255.255.0     192.0.3.2         IF11                3             RIP
  192.0.9.0         255.255.255.0     192.0.3.2         IF11                2             RIP
  192.0.10.0        255.255.255.0     192.0.3.2         IF11                2             RIP
  192.0.12.0        255.255.255.0     192.0.3.2         IF11                2             RIP
```

6.5. *Further readings*

- RIP: IETF RFC number 2453 (www.ietf.org/rfc.html)
- ICMP. IETF RFC number 792 (www.ietf.org/rfc.html).

6.6. *Exercises*

1) Obtain and analyze the graphs that compare the sent RIP traffic for the **Failure** and **NO_Failure** scenarios. Make sure to change the draw style for the graphs to **Bar**.

2) Describe and explain the effect of the failure of the link connecting **Router1** to **Router2** on the routing tables of **Router1**.

3) Create another scenario as a duplicate of the **Failure** scenario. Name the new scenario **Q3_Recover**. In this new scenario have the link connecting **Router1** to **Router2** recover after 400 seconds (make sure to keep the failure that occurs at the 200th second). Generate and analyze the graph that shows the effect of this

recovery on the **Total Number of Updates** in the routing table of **Router1**. Check the contents of **Router1**'s routing table. Compare this table with the corresponding routing tables generated in the **NO_Failure** and **Failure** scenarios.

4) Change the Ping packet size to 5000 bytes (*Hint:* Edit the attributes of the Ping Parameters node). Run the simulation to generate a new Ping report. What is the effect of the new size on the ICMP packet response time?

6.7. *Lab Report*

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

7. Laboratory - OSPF: Open Shortest Path First (A Routing Protocol Based on the Link-State Algorithm)

7.1. *Objective*

The objective of this lab is to configure and analyze the performance of the Open Shortest Path First (OSPF) routing protocol.

7.2. *Overview*

In Lab 6 we discussed RIP, which is the canonical example of a routing protocol built on the distance-vector algorithm. Each node constructs a vector containing the distances (costs) to all other nodes and distributes that vector to its immediate neighbors. Link-state routing is the second major class of intra-domain routing protocol. The basic idea behind link-state protocols is very simple: Every node knows how to reach its directly connected neighbors, and if we make sure that the totality of this knowledge is disseminated to every node, then every node will have enough knowledge of the network to build a complete map of the network.

Once a given node has a complete map for the topology of the network, it is able to decide the best route to each destination. Calculating those routes is based on a well-known algorithm from graph theory - Dijkstra's shortest-path algorithm.

OSPF introduces another layer of hierarchy into routing by allowing a domain to be partitioned into areas. This means that a router within a domain does not necessarily need to know how to reach every network within that domain – it may be sufficient for it to know how to get to the right area. Thus, there is a reduction in the amount of information that must be transmitted to and stored in each node. In addition, OSPF allows multiple routes to the same destination to be assigned the same cost and will cause traffic to be distributed evenly over those routers.

In this lab, you will set up a network that utilizes OSPF as its routing protocol. You will analyze the routing tables generated in the routers and will observe how the resulting routes are affected by assigning areas and enabling load balancing.

7.3. *Prelab Activities*

- Read sections 4.2.3 and 4.2.4 from *"Computer Networks: A Systems Approach"*, 4th *Edition.*

Go to *www.net-seal.net/animations.php* and play the following animation:
- Routing and forwarding.

7.4. *Procedure*

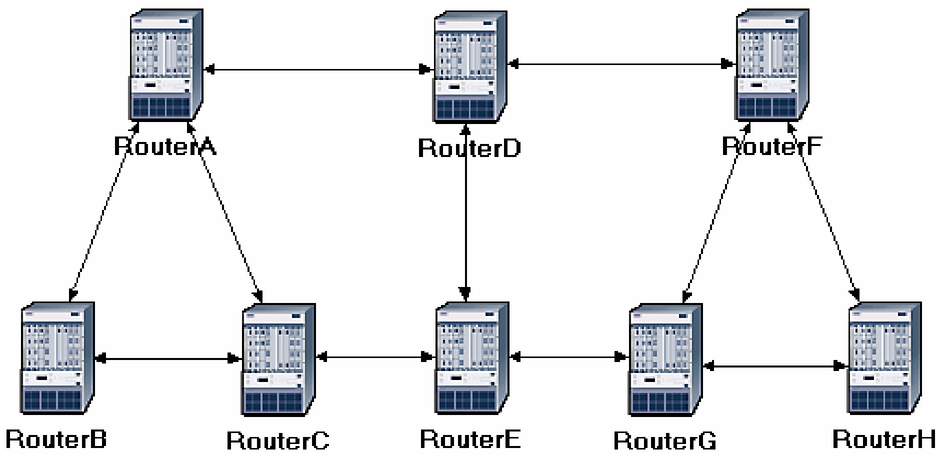
7.4.1. Create a New Project

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

7.4.2. Create and Configure the Network

7.4.2.1. Initialize the Network:

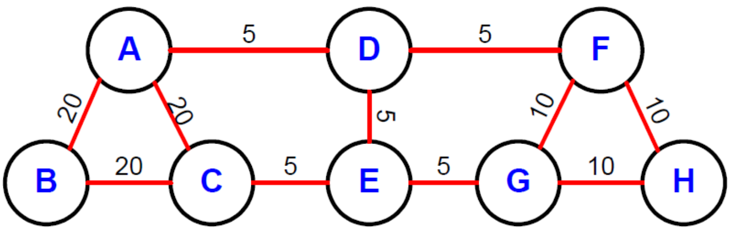
1. The *Object Palette* dialog box should now be on top of your project workspace. If it is not there, open it by clicking . Select the **routers** item from the pull-down menu on the object palette.
   a. Add to the project workspace eight routers of type **slip8_gtwy.** To add an object from a palette, click its icon in the object palette. ⇒ Move your mouse to the workspace and click to place the object. ⇒ You can keep on left-clicking to create additional objects. Right-click when you are finished placing the last object.
2. Switch the palette configuration so it contains the **internet_toolbox**. Use bidirectional **PPP_DS3** links to connect the routers. Rename the routers as shown below.
3. Close the *Object Palette* and then save your project.



> The **slip8_gtwy** node model represents an IP based gateway supporting up to eight serial line interfaces at a selectable data rate. The RIP or OSPF protocols may be used to automatically any dynamically create the gateway's routes in an adaptive manner.
>
> The **PPP_DS3** link has a data of 44.736 Mbps.

7.4.2.2. Configure the Link Costs:

1. We need to assign link costs to match the following graph:

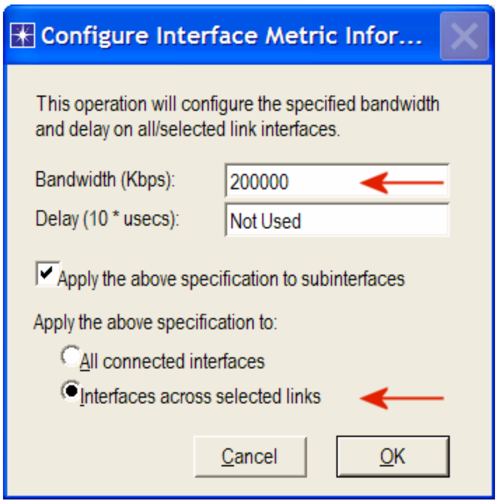


2. Like many popular commercial routers, OPNET router models support a parameter called a *reference bandwidth* to calculate the actual cost, as follows:

   ***Cost* = (*Reference bandwidth*)/(*Link bandwidth*)**

   where the default value of the *reference bandwidth* is 1,000,000 Kbps.

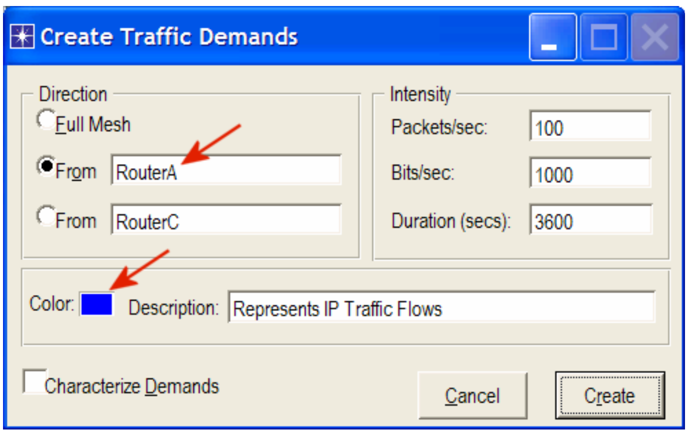
3. For example, to assign a cost of 5 to a link, assign a bandwidth of 200,000 Kbps to that link. Note that this is not the actual bandwidth of the link in the sense of transmission speed, but merely a parameter used to configure link costs.
4. To assign the costs to the links of our network, do the following:
   i. Select all links in your network that correspond to the links with a cost of 5 in the above graph by shift-clicking on them.
   ii. Select the **Protocols** menu ⇒ **IP** ⇒ **Routing** ⇒ **Configure Interface Metric Information**.
   iii. Assign **200,000** to the **Bandwidth (Kbps)** field ⇒ Check the **Interfaces across selected links** radio button, as shown ⇒ Click **OK.**



5. Repeat step 4 for all links with a cost of 10 but assign 100,000 Kbps to the **Bandwidth (Kbps)** field.
6. Repeat step 4 for all links with a cost of 20 but assign 50,000 Kbps to the **Bandwidth (Kbps)** field.
7. Save your project.

7.4.2.3. Configure the Traffic Demands:

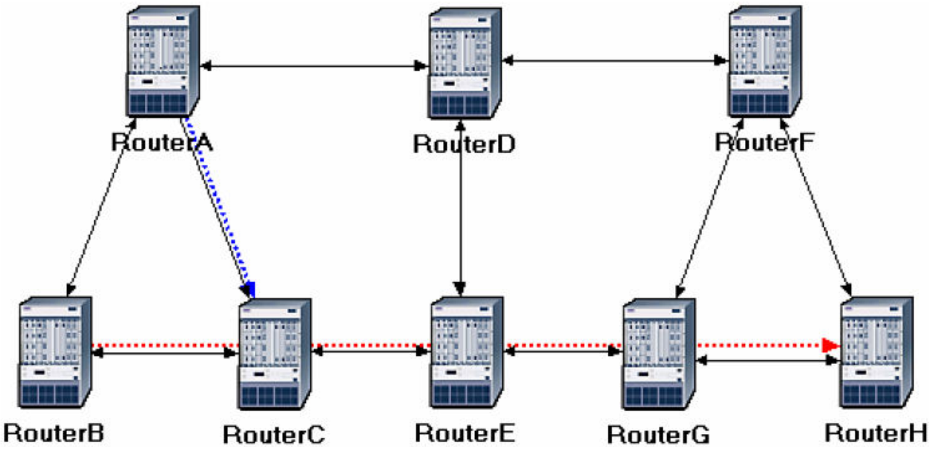
1. Select both **RouterA** and **RouterC** by shift-clicking on them.
   i. Select the **Protocols** menu ⇒ **IP** ⇒ **Demands** ⇒ **Create Traffic Demands** ⇒ Check the **From RouterA** radio button as shown ⇒ Keep the color as blue ⇒ Click **Create**. Now you should see a blue-dotted line representing the traffic demand between **RouterA** and **RouterC.**



2. Select both **RouterB** and **RouterH** by shift-clicking on them.

i. Select the **Protocols** menu ⇒ **IP** ⇒ **Demands** ⇒ **Create Traffic Demands** ⇒ Check the **From RouterB** radio button ⇒ Change the color to **red** ⇒ Click **OK** ⇒ Click **Create**.

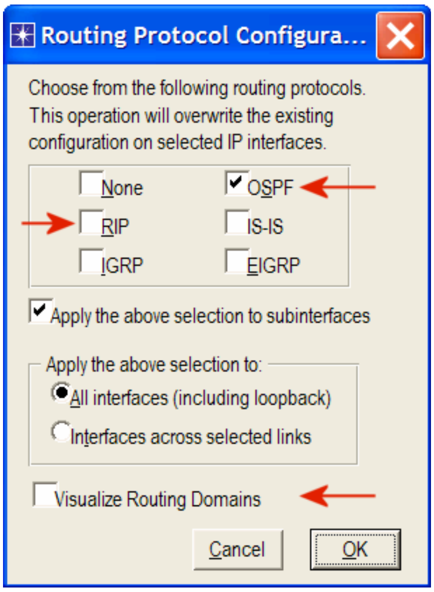
Now you can see the lines representing the traffic demands as shown.



3. To hide these lines: Select the **View** menu ⇒ Select **Demand Objects** ⇒ Select **Hide All**.
4. Save your project.

7.4.2.4. Configure the Routing Protocol and Addresses:

1. Select the **Protocols** menu ⇒ **IP** ⇒ **Routing** ⇒ **Configure Routing Protocols**.
2. Check the **OSPF** check box ⇒ Uncheck the **RIP** check box ⇒ Uncheck the **Visualize Routing Domains** check box, as shown:



3. Click **OK**.
4. Select **RouterA** and **RouterB** only ⇒ Select the **Protocols** menu ⇒ **IP** ⇒ **Routing** ⇒ Select **Export Routing Table for Selected Routers** ⇒ Click **OK** on the *Status Confirm* dialog box.

Auto-Assign IP Addresses assigns a unique IP address to connected IP interfaces whose IP address is currently set to auto-assigned. It does not change the value of manually set IP address.

7.4.3. Configure the Simulation

Here we need to configure some of the simulation parameters:

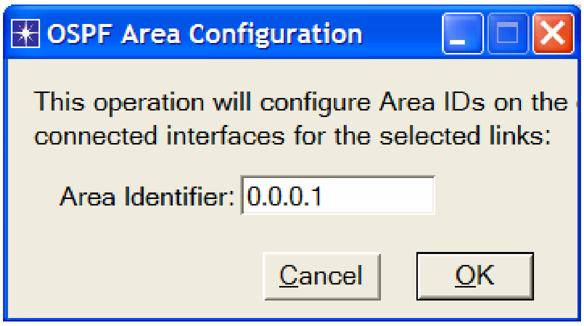
1. Click on  and the *Configure Simulation* window should appear.
2. Set the duration to be **10.0 minutes**.
3. Click **OK** and then save your project.

7.4.4. Duplicate the Scenario

In the network we just created, all routers belong to one level of hierarchy (i.e., one area). Also, we didn't enforce load balancing for any routes. Two new scenarios will be created. The first new scenario will define two new areas in addition to the backbone area. The second one will be configured to balance the load for the traffic demands between **RouterB** and **RouterH**.

7.4.4.1. The Areas Scenario:

1. Select **Duplicate Scenario** from the **Scenarios** menu and give it the name **Areas** ⇒ Click **OK**.
2. Area **0.0.0.1**:
   i. Select the three links that connect **RouterA, RouterB,** and **RouterC** by shift-clicking on them ⇒ Select the **Protocols** menu **OSPF** ⇒ **Configure Areas** ⇒ Assign the value **0.0.0.1** to the **Area Identifier,** as shown ⇒ Click **OK.**

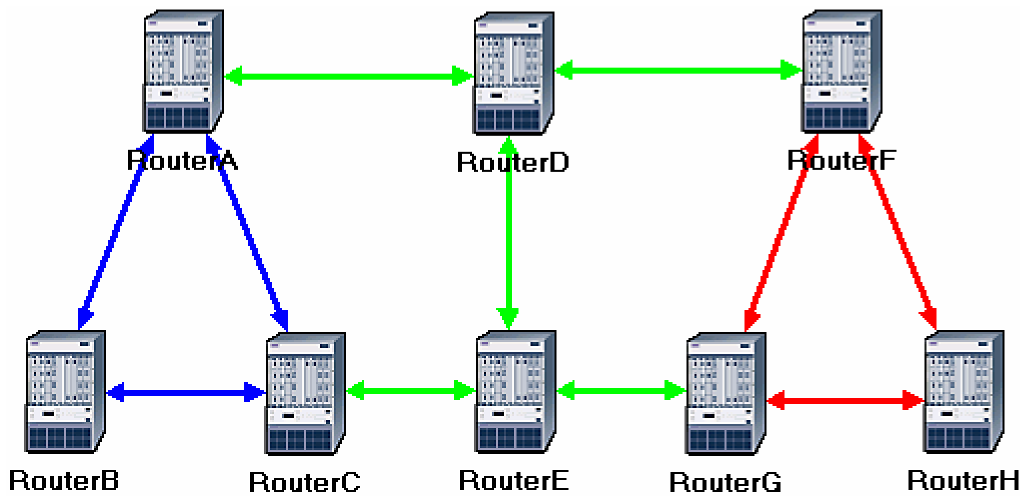
   

   ii. Right-click on **RouterC** ⇒ **Edit Attributes** ⇒ Expand the **OSPF Parameters** hierarchy ⇒ Expand the **Loopback Interfaces** hierarchy ⇒ Expand the **row0** hierarchy ⇒ Assign **0.0.0.1** to the value of the **Area ID** attribute ⇒ Click **OK.**
3. Area **0.0.0.2**
   i. Click somewhere in the project workspace to disable the selected links and then repeat step **2**-i for the three links that connect **RouterF**, **RouterG,** and **RouterH** but assign the value **0.0.0.2** to their **Area Identifier**.
4. To visualize the areas we just created, select the **Protocols** menu ⇒ **OSPF** ⇒ **Visualize Areas** ⇒ Click **OK**. The network should look like the following one with different colors assigned to each area (you may get different colors though).

Loopback interface allows a client and a server on the same host to communicate with each other using TCP/IP.

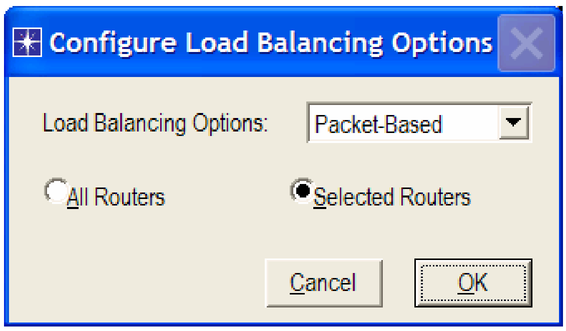
Note:

- The area you did not configure is the backbone area and its **Area Identifier =** 0.0.0.0.
- The figure shows the links with a thickness of 3.



7.4.4.2. The Balanced Scenario:

1. Under the **Scenarios** menu, Switch to **Scenario** ⇒ Select **No_Areas**.
2. Select **Duplicate Scenario** from the **Scenarios** menu, and give it the name **Balanced** ⇒ Click **OK**.
3. In the new scenario, select both **RouterB** and **RouterH** by shift-clicking on them.
4. Select the **Protocols** menu ⇒ **IP** ⇒ **Routing** ⇒ Configure **Load Balancing** Options ⇒ Make sure that the option is **Packet-Based** and the radio button **Selected Routers** is selected as shown ⇒ Click **OK**.



5. Save your project.

OPNET provides two types of IP load balancing.

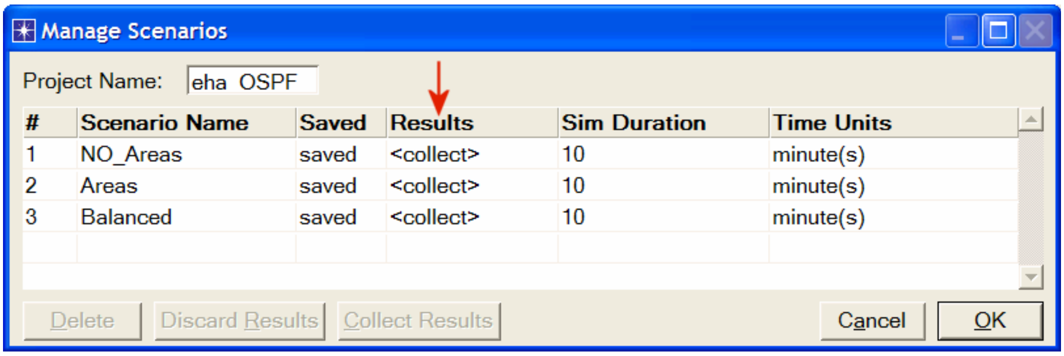
With **Destination Based**, load balancing is done on a per destination basis. The route chosen from the source router to the destination network is the same for all packets.

With **Packet Based**, load balancing is done on a per packet basis. The route chosen from the source router to the destination network is determined for every individual packet.

7.4.5. Run the Simulation

To run the simulation for the three 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.

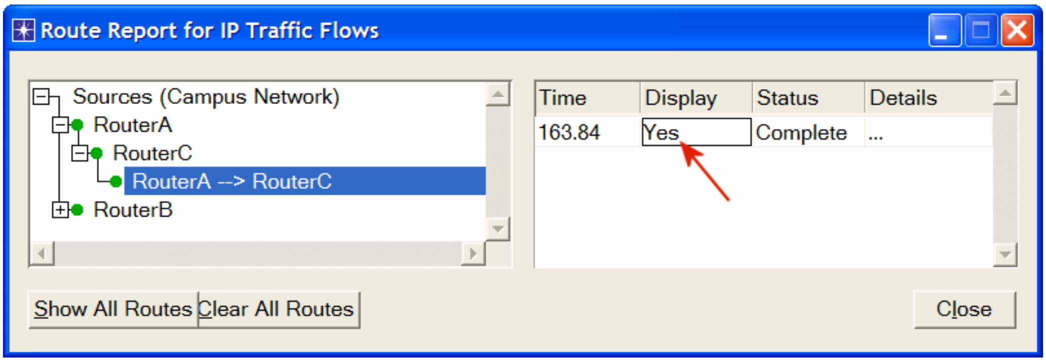


3. Click **OK** to run the three simulations. Depending on the speed of your processor, this may take several seconds to complete.
4. After the three simulation runs complete, one for each scenario, click **Close** and then save your project.

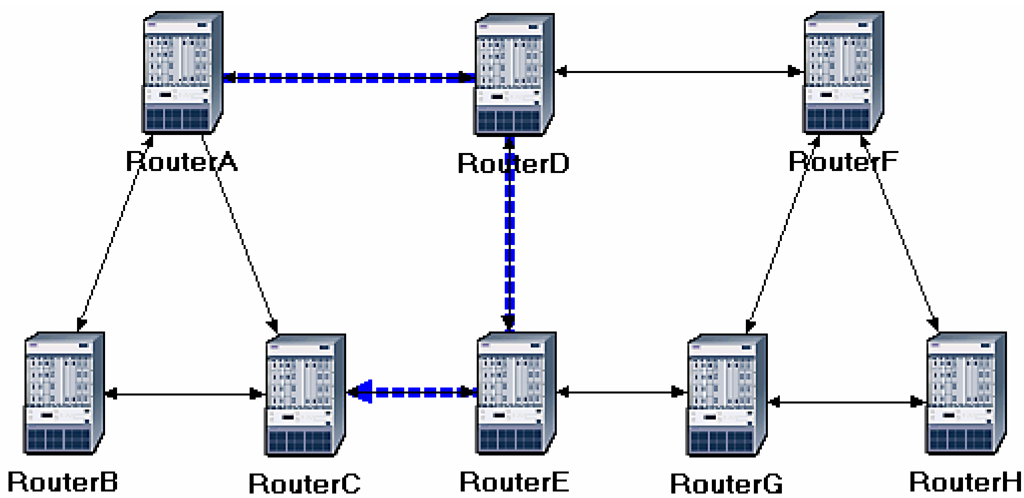
7.4.6. View the Results

7.4.6.1. The No_Areas Scenario:

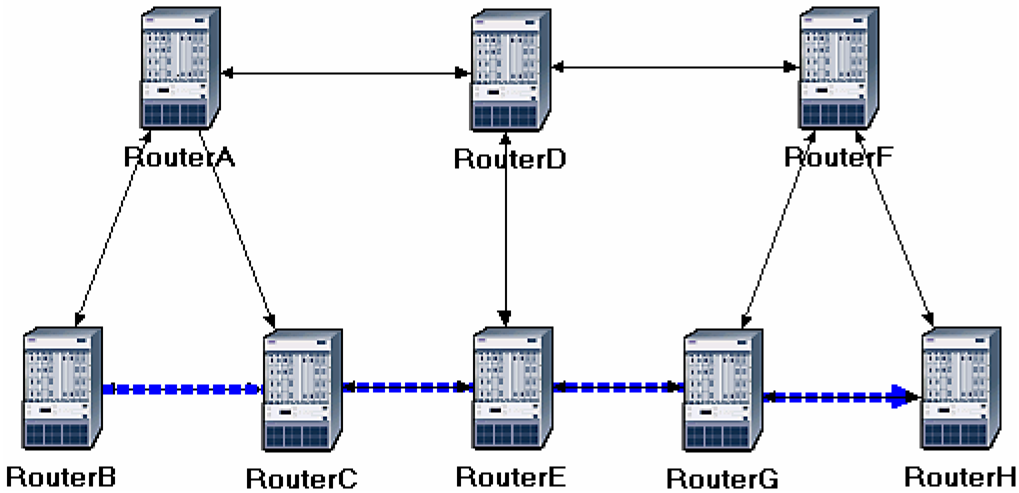
1. Go back to the **No_Areas** scenario.
2. To display the route for the traffic demand between **RouterA** and **RouterC**: Select the **Protocols** menu ⇒ **IP** ⇒ **Demands** ⇒ **Display Routes** for **Configured Demands.** ⇒ Expand the hierarchies as shown and select **RouterA → RouterC** ⇒ Go to the **Display** column and pick **Yes** ⇒ Click **Close**.



3. The resulting route will appear on the network as shown:

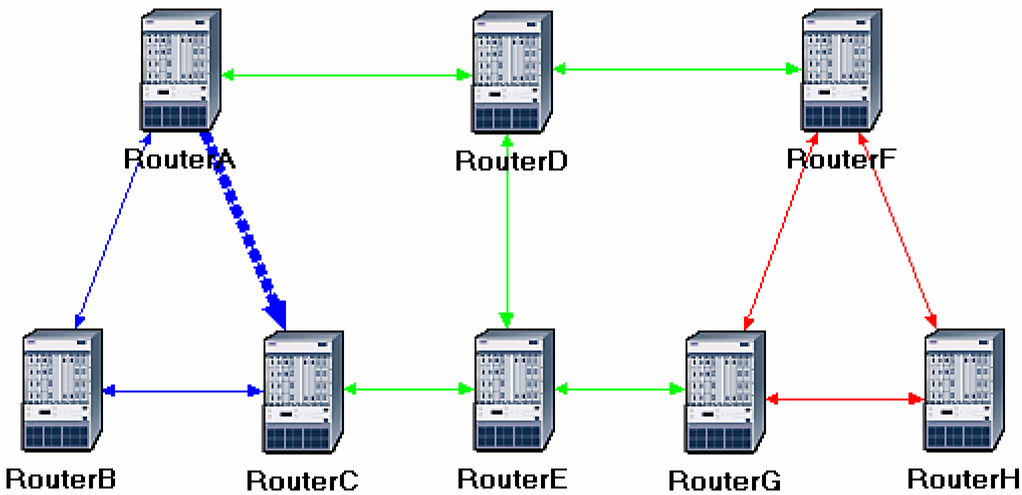


4. Repeat step 2 to show the route for the traffic demand between **RouterB** and **RouterH**. The route is as shown below. (Note: Depending on the order in which you created the network topology, the other “equal-cost” path can be used, that is, the *RouterB-RouterA-RouterD-RouterF-RouterH* path).



7.4.6.2. *The Areas Scenario:*

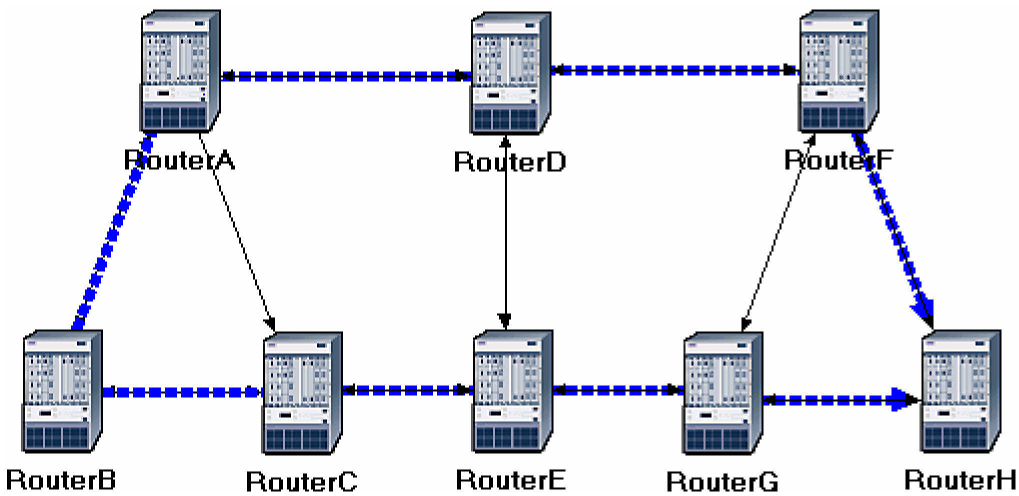
1. Go to scenario **Areas**.
2. Display the route for the traffic demand between **RouterA** and **RouterC**. The route is as shown:



3. Save your project.

7.4.6.3. *The Balanced Scenario:*

1. Go to scenario **Balanced**
2. Display the route for the traffic demand between **RouterB** and **RouterH**. The route is as shown:



3. Save your project.

7.5. *Further readings*

1. OPNET [OSPF Model Description]: From the **Protocols** menu, select **OSPF** ⇒ Model Usage Guide.
2. OSPF: IETF RFC number 2328 (www.ietf.org/rfc.html).

7.6. *Exercises*

1) Explain why, for the same pair of routers, the **Areas** and **Balanced** scenarios result in different routes than those observed in the **No_Areas** scenario.
2) Using the simulation log, examine the generated routing table in **RouterA** for each one of the three scenarios. Explain the values assigned to the *Metric* column of each route.

Hints:

Refer to the *View Results* section in Lab 6 for information about examining the routing tables. You will need to set the global attribute **IP Interface Addressing Mode** to the value **Auto Addressed/Export** and rerun the simulation.

To determine the IP address information for all interfaces, you need to open the *Generic Data File* that contains the IP addresses and associated with the scenarios.

3) OPNET allows you to examine the link-state database that is used by each router to build the directed graph of the network. Examine this database for **RouterA** in the **No_Areas** scenario. Show how **RouterA** utilizes this database to create a map for the topology of the network and draw this map (This is the map that will be used later by the router to create its routing table.)

Hints:

- To export the link-state database of a router, **Edit** the attributes of the router and set the **Link State Database Export** parameter (one of the **OSPF Parameters,** under **Processes)** to **Once at End of Simulation**.
- You will need to set the global attribute **IP Interface Addressing Mode** to the value **Auto Addressed/Export.** This will allow you to check the automatically assigned IP addresses to the interfaces of the network. (Refer to the notes of exercise 2 above.)
- After rerunning the simulation, you can check the link-state database by opening the simulation log (from the **Results** menu). The link-state database is available in **Classes** ⇒ **OSPF** ⇒ **LSDB_Export**.

4) Create another scenario as a duplicate of the **No_Areas** scenario Name the new scenario **Q4_No_Areas_Failure**. In this new scenario simulate a failure of the link connecting **RouterD** and **RotuerE**. Have this failure start after 100 seconds. Read the simulation. Show how that link failure affects the content of the link-state database and routing table of **RouterA**. (You will need to disable the global attribute **OSPF Sim Efficiency**. This will allow OSPF to update the routing table if there is any change in the network.)
5) For both **No_Areas** and **Q4_No_Areas_Failure** scenario, collect the **Traffic Sent (bits/sec)** statistic (one of the Global Statistics under OSPF). Rerun the simulation for these two scenarios and obtain the graph that compares the

OSPF's **Traffic Sent (bits/sec)** in both scenarios. Comment on the obtained graph.

Note: A stub network only carries local traffic (i.e., packets to and from local hosts). Even if it has paths to more than one other network, it does not carry traffic for other networks (RFC 1983).

7.7. *Lab Report*

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

8. Laboratory - Border Gateway Protocol (BGP) (An Interdomain Routing Protocol)

8.1. *Objective*

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

8.2. *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 employs its own *intradomain* routing protocol (e.g., RIP or OSPF). Different ASs establish routes among each other through *interdomain* routing protocols. The border gateway protocol (BGP) is one of the major 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 also 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. 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 intradomain routing protocol and BGP as the interdomain one. You will analyze the routing tables generated in the routers as well as the effect of applying a simple policy.

8.3. *Prelab Activities*

- Read section 4.3 from ***"Computer Networks: A Systems Approach",*** 4th ***Edition.***

  Go to ***www.net-seal.net/animations.php*** and play the following animation:
  - IP Subnets.

8.4. *Procedure*

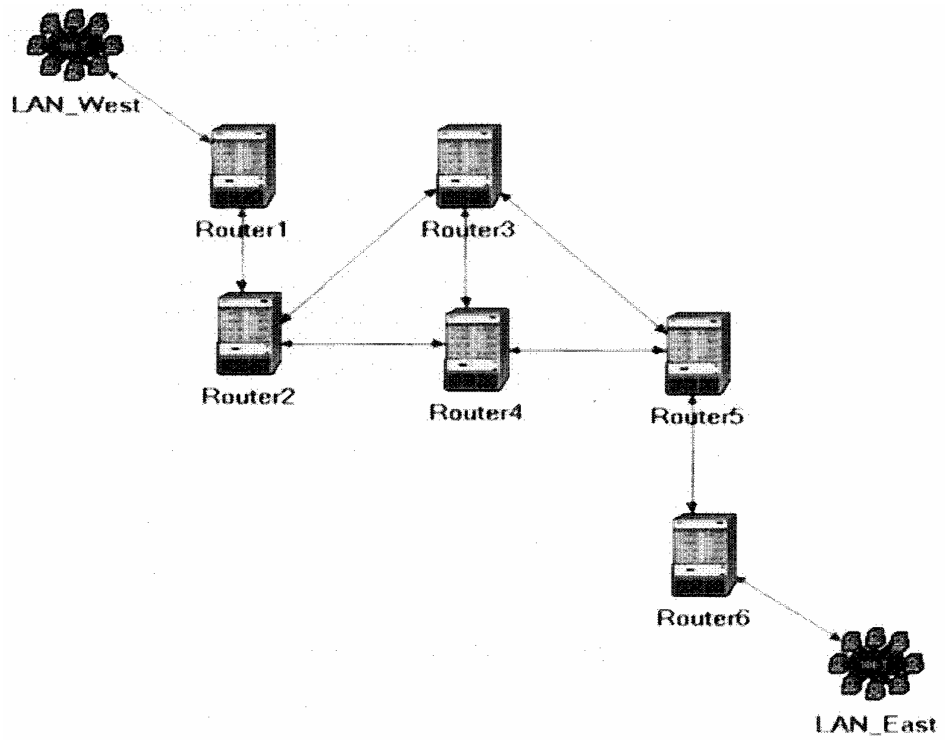
8.4.1. Create a New Project

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 **Campus** from the *Network Scale* list ⇒ Click **Next** three times ⇒ Click **OK**.

8.4.2. Create and Configure the Network

8.4.2.1. Initialize 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 in the following figure. Also, rename the network 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 in the following figure.
5. Close the *Object Palette* dialog box.
6. Save your project.



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.

8.4.2.2. Routers Configuration:

1. Highlight or select simultaneously (using shift- and left-click) all six routers ⇒ 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:
   i. **Redistribution → Routing Protocols → RIP → Redistribute w/ Default.**

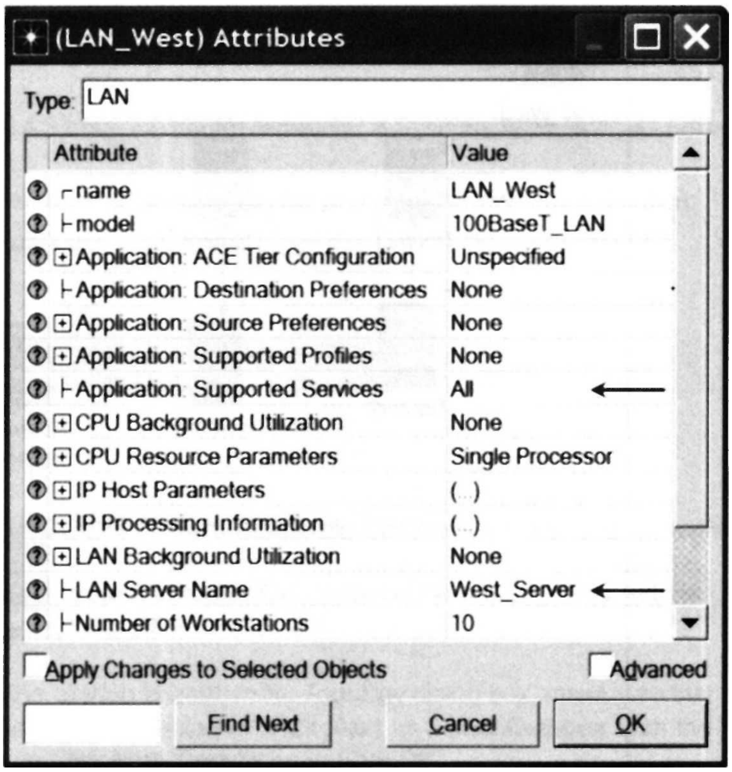
3. Expand the **IP Routing Parameters** hierarchy and set the following:
   i. **Routing Table Export = Once at End of Simulation.** This asks the router to export its routing table at the end of the simulation to the *simulation log.*
4. Expand the **RIP Parameters** hierarchy and set the following: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

Redistribute w/ Default allows router to have a route to a destination that belongs to another Autonomous System.

8.4.2.3. 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.



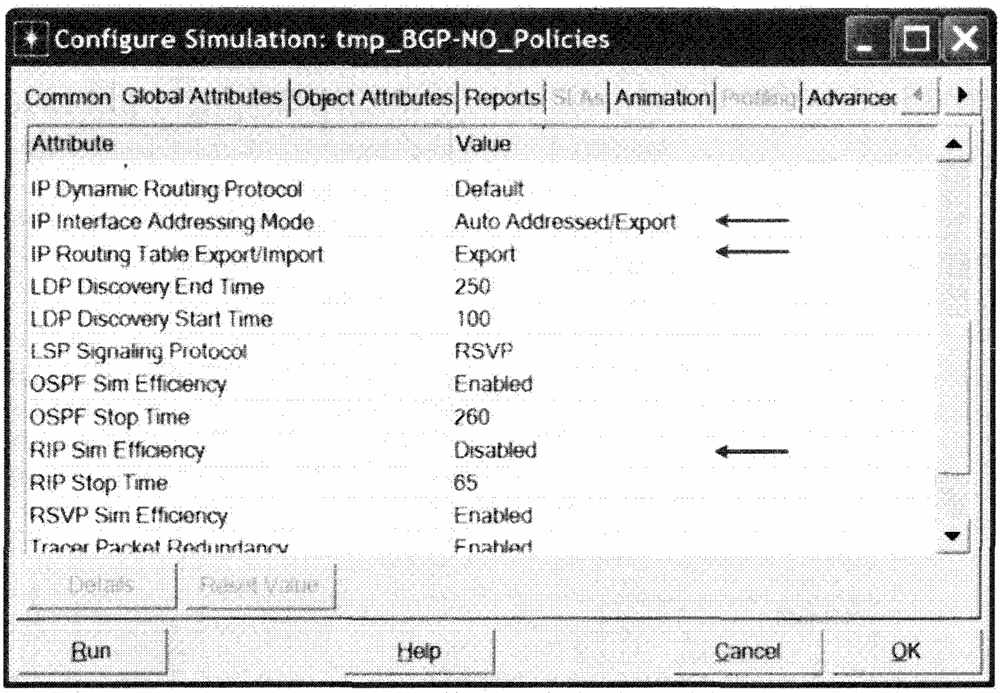
2. Right-click on **LAN_East** ⇒ **Edit Attributes**:
   i. Expand the **Application: Supported Profiles** hierarchy ⇒ Set **rows** to **1** ⇒ Expand the **row 0** hierarchy ⇒ Set **Profile Name** to **E-commerce Customer**.
   ii. Edit the **Application: Destination Preferences** attribute as follows:

   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 then save your project.

8.4.3. 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 be **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 the 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.



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.

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

8.4.4. Choose the Statistics

1. Right-click on **LAN_East** and select **Choose Individual Statistics** from the pop-up menu ⇒ 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.

4. Save your project.

8.4.5. 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  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 Directorie**s. 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 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 Loop-back interface as shown. Create a similar table for your project but note that your result may vary due to different nodes placement.

Table 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: 11 IP: 192.0.1.1				
2	IF: 10 IP: 192.0.1.2	IF: 12 IP: 192.0.8.1	IF:11 IP: 192.0.4.2	IF:4 IP: 192.0.7.1		
3		IF: 10 IP: 192.0.4.1	IF: 12 IP: 192.0.6.1	IF: 11 IP: 192.0.5.1	IF: 4 IP: 192.0.3.1	
4		IF: 10 IP: 192.0.7.2	IF: 11 IP: 192.0.5.2	IF: 12 IP: 192.010.1	IF 4 IP: 192.0.9.1	
5			IF: 10 IP: 192.0.3.2	IF: 11 IP: 192.0.9.2	IF: 12 IP: 192.0.12.1	IF: 4 IP: 1920.11.1
6					IF: 10 IP: 192.0.11.2	IF: 12 IP: 192.0.14.1

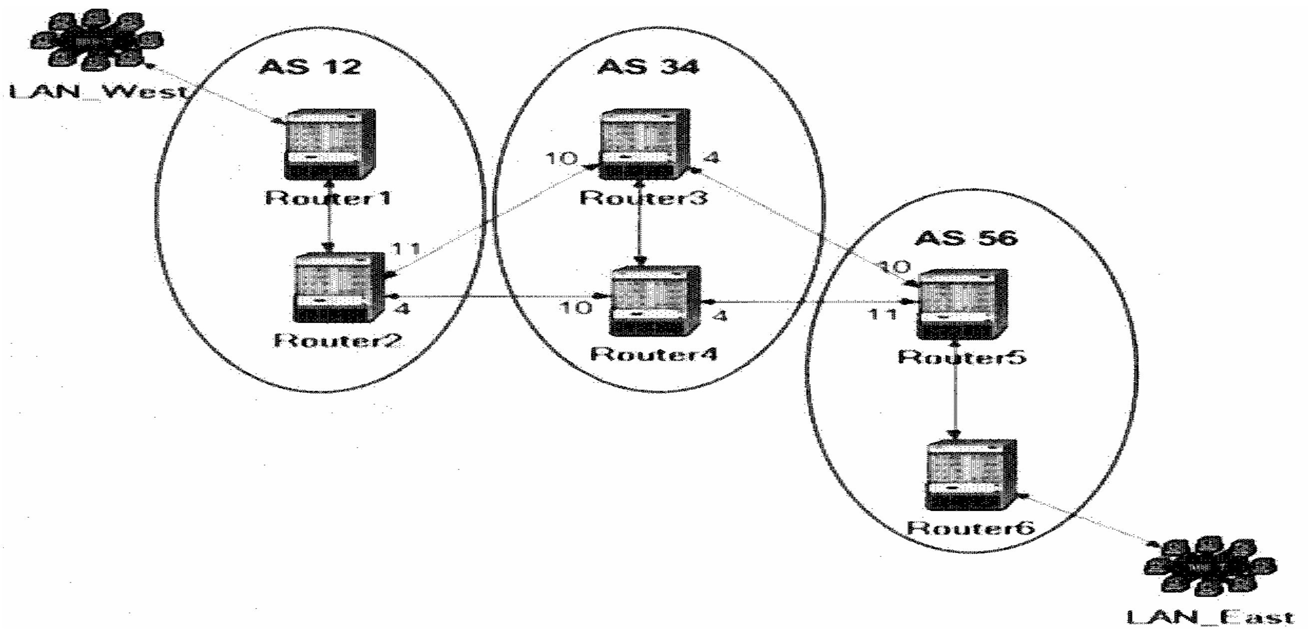
8.4.6. Creating the BGP Scenario

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.

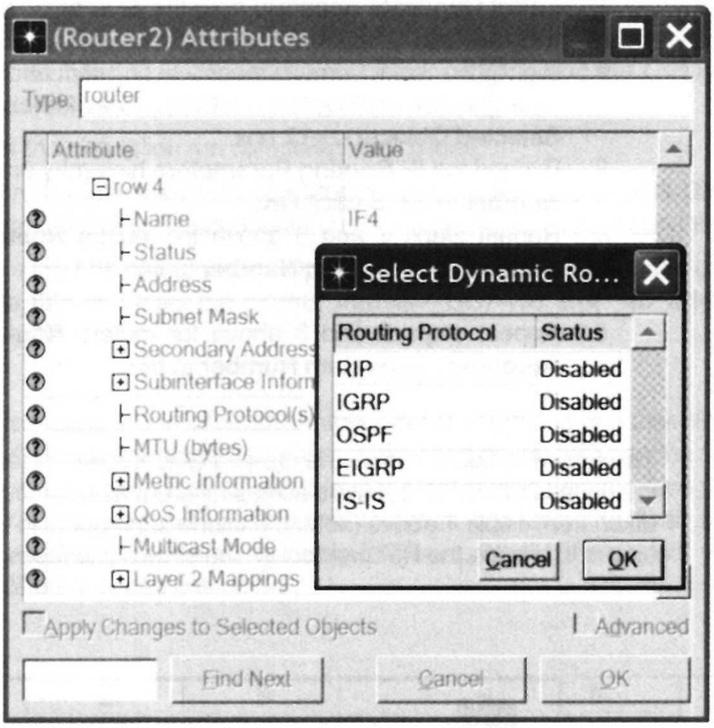
1. Select **Duplicate Scenario** from the **Scenarios** menu and name it **BGP_Simple** ⇒ Click **OK.**

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 above for routers **Router3** and **Router4**. Assign their **Autonomous System Number** to **34**.
5. Repeat steps 2 and 3 above for routers **Router5** and **Router6**. Assign their **Autonomous System Number** to **56**.

The following figure shows the created autonomous systems. The figure shows also the interfaces that connect routers across different autonomous systems. There interfaces are taken from Table 1 above (note: the interface numbers in your project may vary). The next step is to disable the RIP protocol on the shown interfaces.



6. 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.



7. Repeat step 6 above for all other interfaces that connect routers across autonomous systems (i.e., All the eight inter-domain interfaces shown above).
8. Save your project.

8.4.7. 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 inter-domain routers. Therefore, no routing tables are created to deliver packets among autonomous systems. The solution is to utilize BGP by defining the neighbors of inter-domain routers. Table 2 shows the neighbors of the routers that will run BGP. Neighbors are defined by their interface IP address and the AS number. For each router in Table 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 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 will collect in your Table 1.

2. Save your project.

Table 2: Neighbors' info for inter-domain routers.

Routers	BGP Parameters ⇒ Neighbor Information		
	row 0	row 1	row 2
Router1	IP Address: 192.0.8.1 Remote AS: 12 Update Source: Loopback		
Router2	IP Address 192.0.4.1 Remote AS: 34 Update Source Not Used	IP Address: 192.0.7.2 Remote AS: 34 Update Source Not Used	IP Address: 192.0.2.1 Remote AS: 12 Update Source: Loopback

Routers	BGP Parameters ⇒ Neighbor Information		
	row 0	row 1	row 2
Router3	IP Address 192.0.4.2 Remote AS: 12 Update Source Not Used	IP Address: 192.0.3.2 Remote AS: 56 Update Source: Not Used	IP Address: 192.0.10.1 Remote AS: 34 Update Source: Loopback
Router4	IP Address: 192.0.7.1 Remote AS: 12 Update Source: Not Used	IP Address: 192 0.9.2 Remote AS: 56 Update Source: Not Used	IP Address: 192.0.6.1 Remote AS: 34 Update Source: Loopback
Router5	IP Address: 192.0.3.1 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		

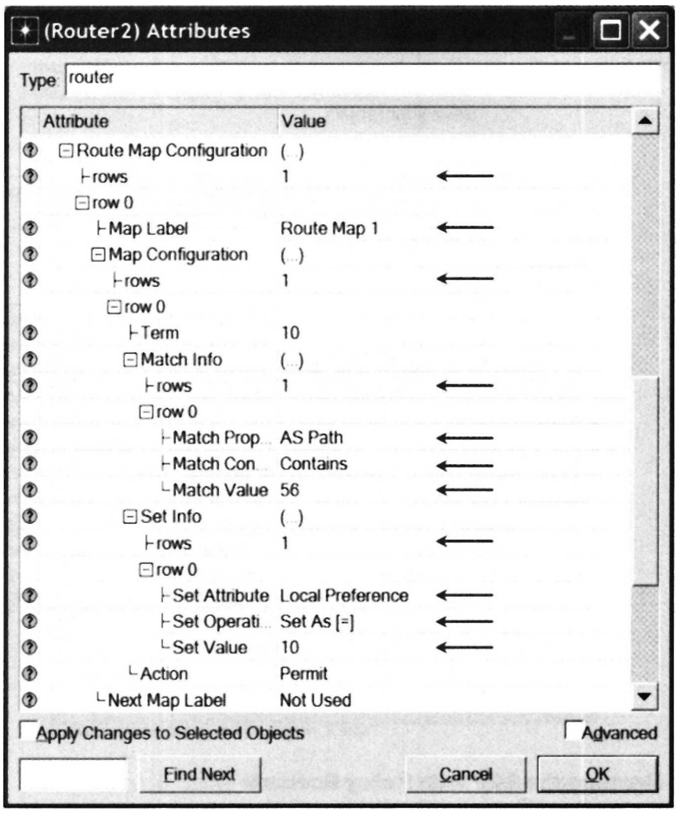
8.4.8. Creating the BGP with Policy Scenario

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. First 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**.

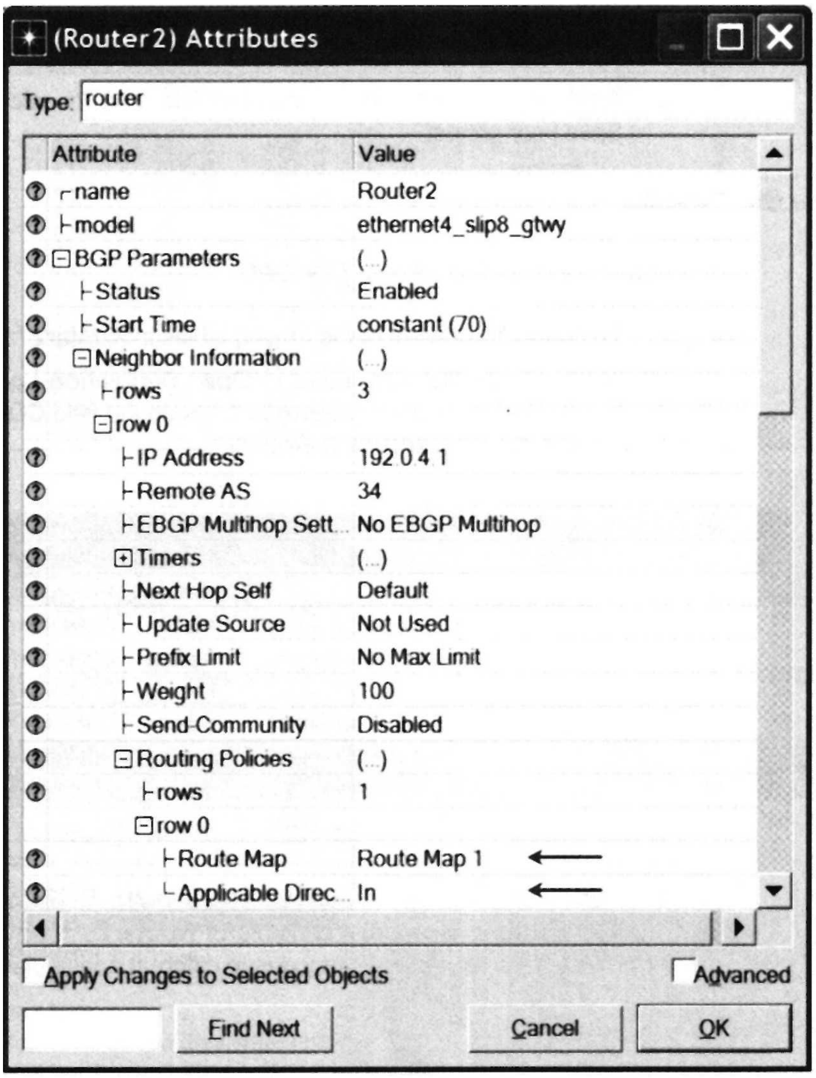
2. Right-click on **Router2** ⇒ **Edit Attributes** ⇒ Expand the **IP Routing Parameters** hierarchy ⇒ Expand the **Route Map Configuration** hierarchy. ⇒ Set the attributes as shown in the following figure.

   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 AS that should be crossed to reach the destination).



The next step is to assign the above 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.

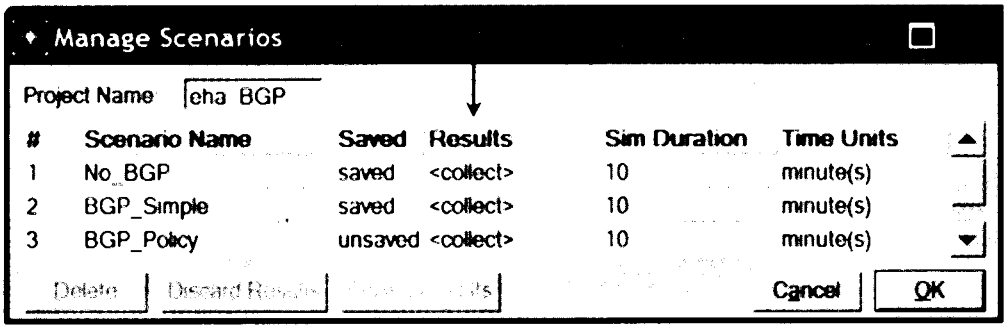
3. Right-click on **Router2** ⇒ **Edit Attributes** ⇒ Expand the **BGP Parameters** hierarchy ⇒ Expand the **Neighbor Information** hierarchy ⇒ Expand the row that has the IP address of **Router3** interface (it is **row 0** in my project) ⇒ Expand the **Routing Policies** hierarchy ⇒ Set its attribute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



8.4.9. Run the Simulation

To run the simulation for the three scenarios simultaneously:

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

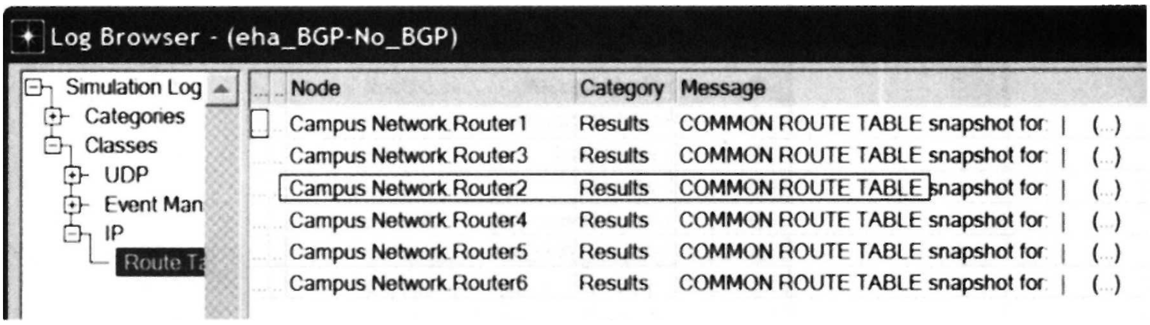


3. Click **OK** to run the three simulations. Depending on the speed of your processor, this may take several minutes to complete.
4. After the three simulation runs complete, one for each scenario, click **Close.** ⇒ Save your project.

8.4.10. View the Results

8.4.10.1. Compare the Routing Tables Content:

1. To check the content of the routing tables in **Router2** for both scenarios:
   i. Go to the **Results** menu ⇒ Open **Simulation Log** ⇒ Expand the hierarchy on the left as shown below ⇒ Click on the field **COMMON ROUTE TABLE** in the row corresponds to **Router2**.



2. Carry out the previous step for scenario **No_BGP** and scenario **BGP_Simple**. The following are partial contents of **Router2**'s routing table for both scenarios (Note: Your results may vary due to different nodes placement):

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

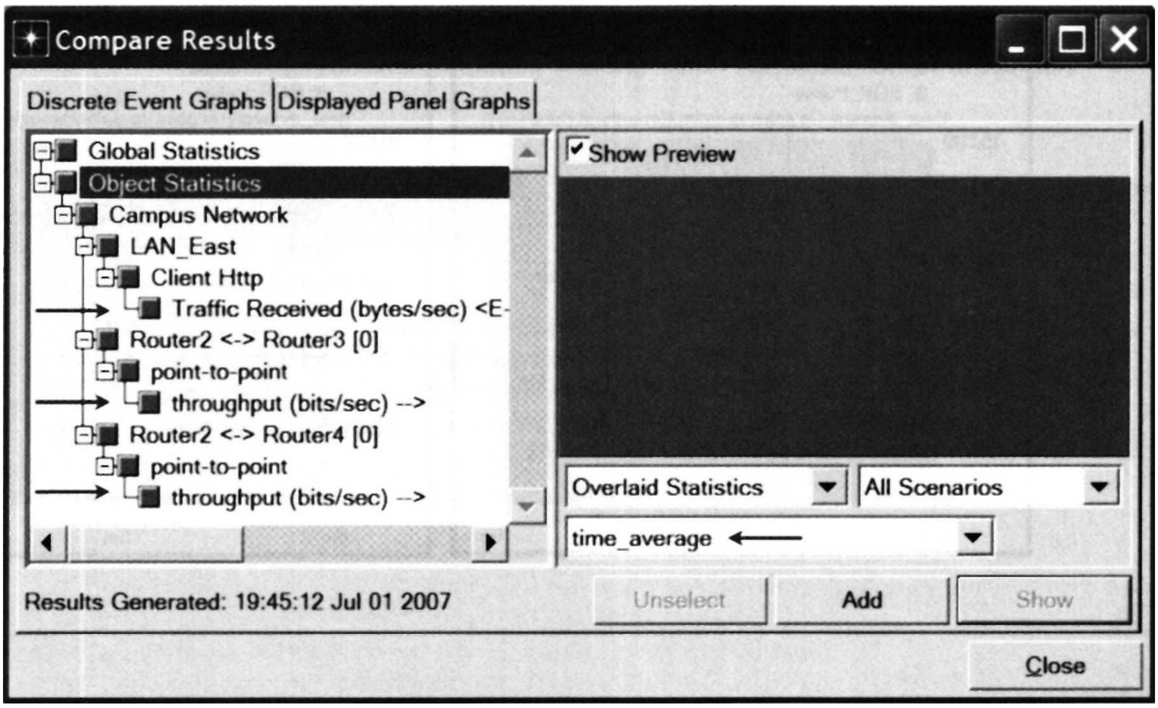
Dest. Address	Subnet Mask	Next Hop	Interface Name	Metric	Protocol
192.0.7.0	255.255.255.0	192.0.7.1	IF4	0	Direct
192.0.1.0	255.255.255.0	192.0.1.2	IF10	0	Direct
192.0.4.0	255.255.255.0	192.0.4.2	IF11	0	Direct
192.0.8.0	255.255.255.0	192.0.8.1	Loopback	0	Direct
192.0.0.0	255.255.255.0	192.0.1.1	IF10	1	RIP
192.0.2.0	255.255.255.0	192.0.1.1	IF10	1	RIP
192.0.5.0	255.255.255.0	192.0.7.2	IF4	1	RIP
192.0.9.0	255.255.255.0	192.0.7.2	IF4	1	RIP
192.0.10.0	255.255.255.0	192.0.7.2	IF4	1	RIP
192.0.3.0	255.255.255.0	192.0.4.1	IF11	1	RIP
192.0.6.0	255.255.255.0	192.0.4.1	IF11	1	RIP
192.0.11.0	255.255.255.0	192.0.4.1	IF11	2	RIP
192.0.12.0	255.255.255.0	192.0.4.1	IF11	2	RIP
192.0.13.0	255.255.255.0	192.0.4.1	IF11	3	RIP
192.0.14.0	255.255.255.0	192.0.4.1	IF11	3	RIP

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

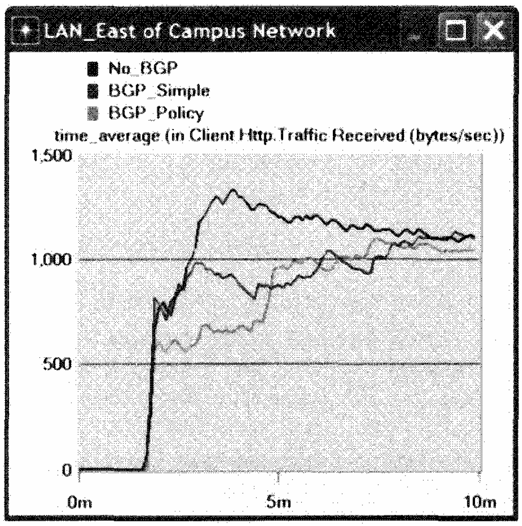
Dest. Address	Subnet Mask	Next Hop	Interface Name	Metric	Protocol
192.0.1.0	255.255.255.0	192.0.1.2	IF10	0	Direct
192.0.8.0	255.255.255.0	192.0.8.1	Loopback	0	Direct
192.0.7.0	255.255.255.0	192.0.7.1	IF4	0	Direct
192.0.4.0	255.255.255.0	192.0.4.2	IF11	0	Direct
192.0.0.0	255.255.255.0	192.0.1.1	IF10	1	RIP
192.0.2.0	255.255.255.0	192.0.1.1	IF10	1	RIP
192.0.10.0	255.255.255.0	192.0.7.2	IF4	0	BGP
192.0.5.0	255.255.255.0	192.0.4.1	IF11	0	BGP
192.0.6.0	255.255.255.0	192.0.4.1	IF11	0	BGP
192.0.9.0	255.255.255.0	192.0.4.1	IF11	2	BGP
192.0.3.0	255.255.255.0	192.0.4.1	IF11	2	BGP
192.0.11.0	255.255.255.0	192.0.4.1	IF11	0	BGP
192.0.12.0	255.255.255.0	192.0.4.1	IF11	0	BGP
192.0.13.0	255.255.255.0	192.0.4.1	IF11	0	BGP
192.0.14.0	255.255.255.0	192.0.4.1	IF11	0	BGP

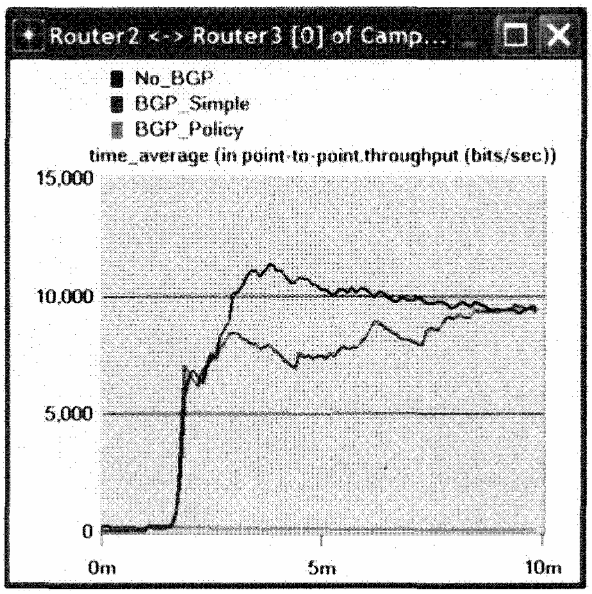
8.4.10.2. Compare the load in the network:

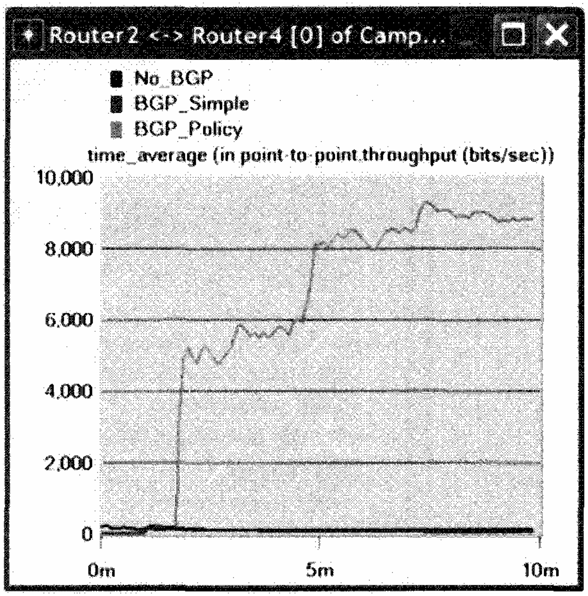
1. Select **Compare Results** from the **Results** menu.
2. Change the drop-down menu in the right-lower part of the **Compare Results** dialog box from **As Is** to **time_average** as shown.



3. Select and show the graphs of the following statistics: **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 below.







8.5. *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).
- BGP4 Protocol Analysis: IETF RFC number 1774 (www.ietf.org/rfc.html).

8.6. *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 **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 intra-domain routing protocol in **AS 56** to be **OSPF** instead of **RIP.** Run the new scenario and check the contents of **Router5**'s routing table. Analyze the content of this table.

8.7. *Lab Report*

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

9. Laboratory - TCP: Transmission Control Protocol (A Reliable, Connection-Oriented, Byte-Stream Service)

9.1. *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.

9.2. *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 the source 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 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.

9.3. *Prelab Activities*

- Read sections 5.1 and 5.2 from *"Computer Networks: A Systems Approach",* 4th *Edition*.

  Go to ***www.net-seal.net/animations.php*** and play the following animations:
  - TCP Connections.
  - TCP Multiplexing.
  - TCP Buffering and Sequencing.
  - User Datagram Protocol (UDP).

9.4. *Procedure*

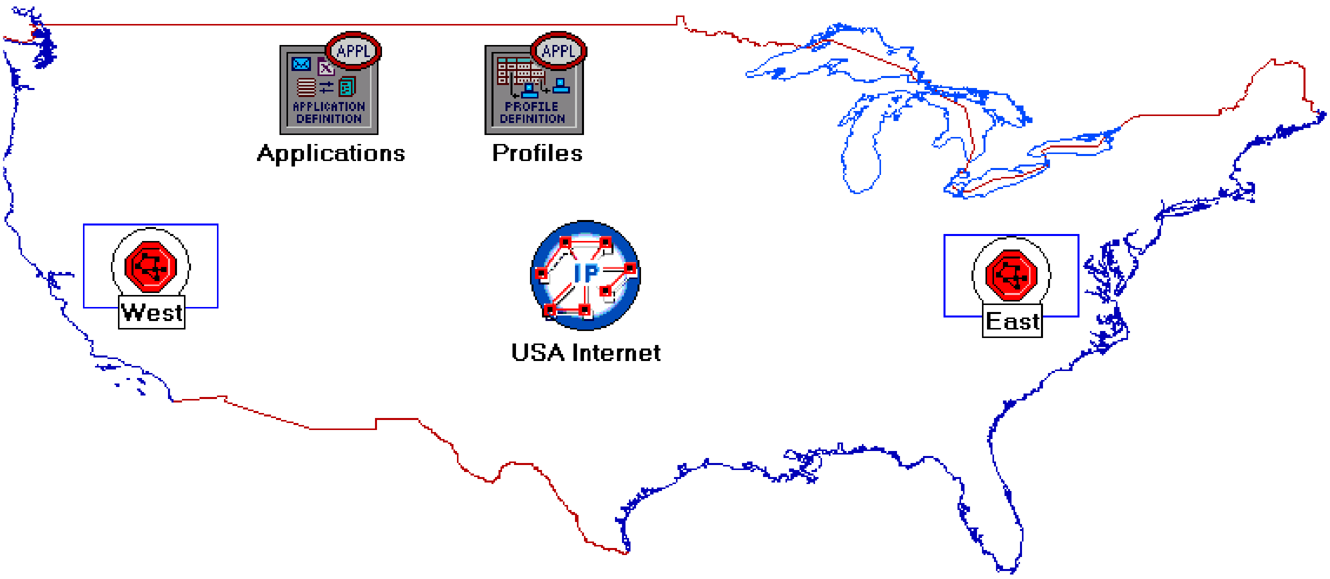
9.4.1. Create a New Project

1. Start OPNET IT Guru Academic Edition ⇒ Choose New from the File menu.
2. Select Project and Click OK ⇒ Name the project **<your initials>**_TCP, and the scenario No_Drop ⇒ Click OK.
3. In the Startup Wizard: Initial Topology dialog box, make sure that Create Empty Scenario is selected ⇒ Click Next - ⇒ Select Choose From Maps from the Network Scale list ⇒ Click Next ⇒ Choose USA from the Map List ⇒ Click Next twice ⇒ Click OK.

9.4.2. Create and Configure the Network

9.4.2.1. Initialize the Network:

1. The *Object Palette* dialog box should now be on the top of your project space. If it is not there, open it by clicking . Make sure that the internet_toolbox item is selected from the pull-down menu on the object palette.
2. Add to the project workspace the following objects from the palette: Application Config, Profile Config, an ip32_Cloud, and two subnets.
   a. To add an object from a palette, click its icon in the object palette ⇒ Move your mouse to the workspace ⇒ Click to drop the object in the desired location ⇒ Right-click to finish creating objects of that type.
3. Close the palette.
4. Rename the objects you added as shown and then save your project:

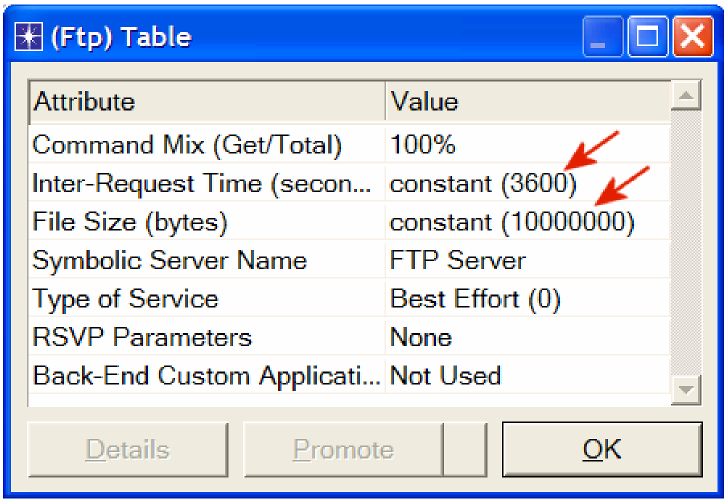


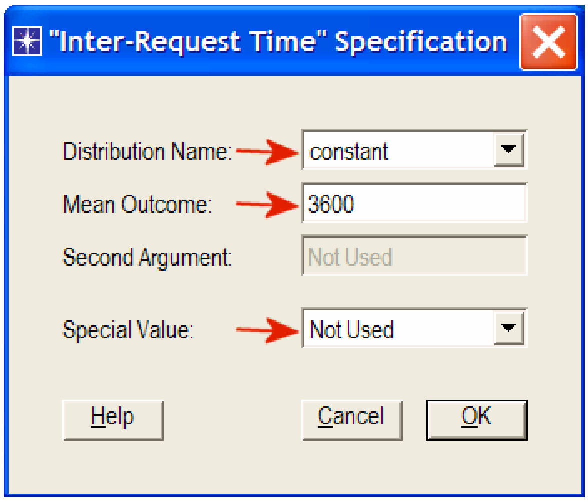
The **ip32_cloud** node model represents an IP cloud supporting up to 32 serial line interfaces at a selectable data rate through which IP traffic can be modeled. IP packets arriving on any cloud interface are routed to the appropriate output interface based on their destination IP address. The RIP or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

9.4.2.2. Configure the Applications:

1. Right-click on the Applications node ⇒ **Edit** Attributes ⇒ Expand the Application Definitions attribute and set rows to 1 ⇒ Expand the new row ⇒ Name the row FTP_Application.

   i. Expand the **Description** hierarchy. ⇒ Edit the **FTP** row as shown (you will need to set the **Special Value** to **Not Used** while editing the shown attributes):



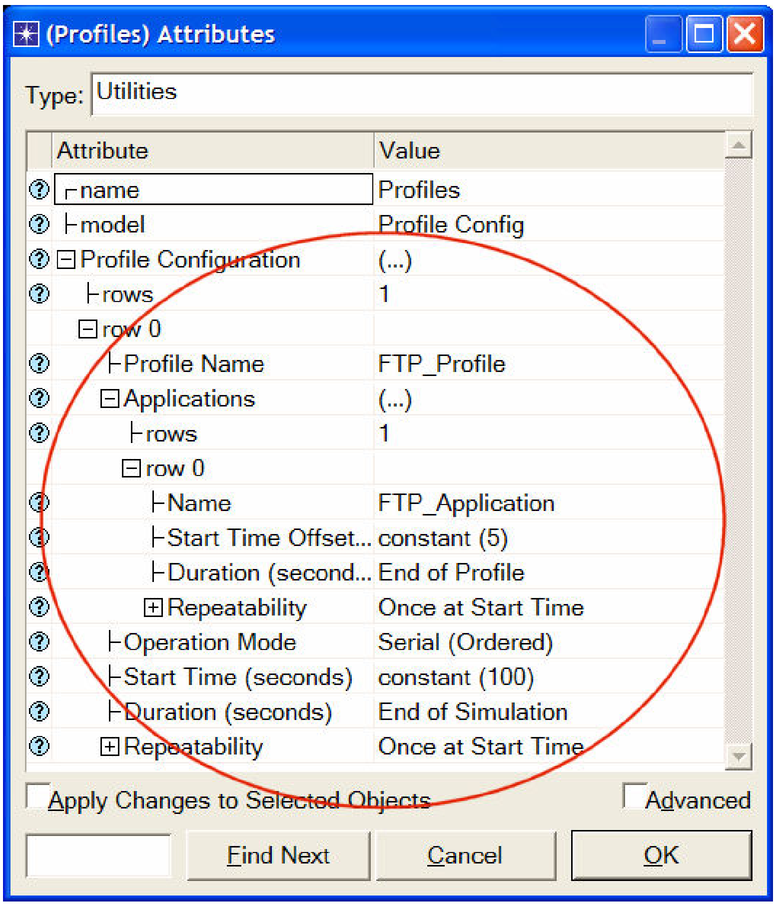


2. Click OK twice and then save your project.

9.4.2.3. Configure the Profiles:

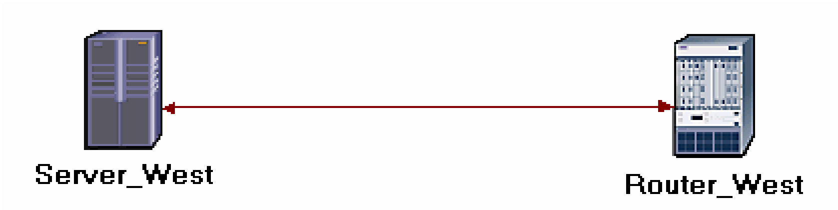
1. Right-click on the Profiles node ⇒ **Edit** Attributes ⇒ Expand the Profile Configuration attribute and set rows to 1.

   i. Name and set the attributes of **row 0** as shown ⇒ Click **OK**.



9.4.2.4. Configure the West Subnet:

1. Double-click on the West subnet node. You get an empty workspace, indicating that the subnet contains no objects.
2. Open the object palette  and make sure that the internet_toolbox item is selected from the pull-down menu.
3. Add the following items to the subnet workspace: one ethernet_server, one ethernet4_slip8_gtwy router, and connect them with a bidirectional 100_BaseT link ⇒ Close the palette ⇒ Rename the objects as shown.



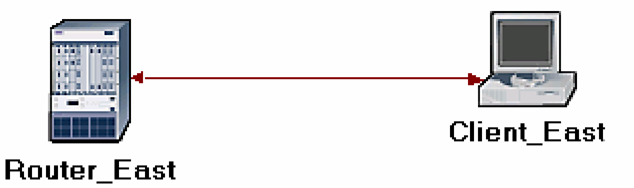
The **ethernet4_slip8_gtwy** mode model represents an IP-based gateway supporting four Ethernet hub interfaces and eight serial line interfaces.

1. Right-click on the Server_West node ⇒ **Edit** Attributes:
   i. Edit **Application: Supported Services** ⇒ Set **rows** to **1** ⇒ Set **Name** to **FTPApplication** ⇒ Click **OK.**
   ii. Edit the value of the **Server Address** attribute and write down **Server_West.**
   iii. Expand the **TCP Parameters** hierarchy ⇒ Set both **Fast Retransmit** and **Fast Recovery** to **Disabled.**
2. 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.

9.4.2.5. 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 ⇒ Set **rows** to **1** ⇒ Expand the **row 0** hierarchy ⇒ Set **Profile Name** to **FTP_Profile.**
   ii. Assign **Client_ East** to the **Client Address** attributes.

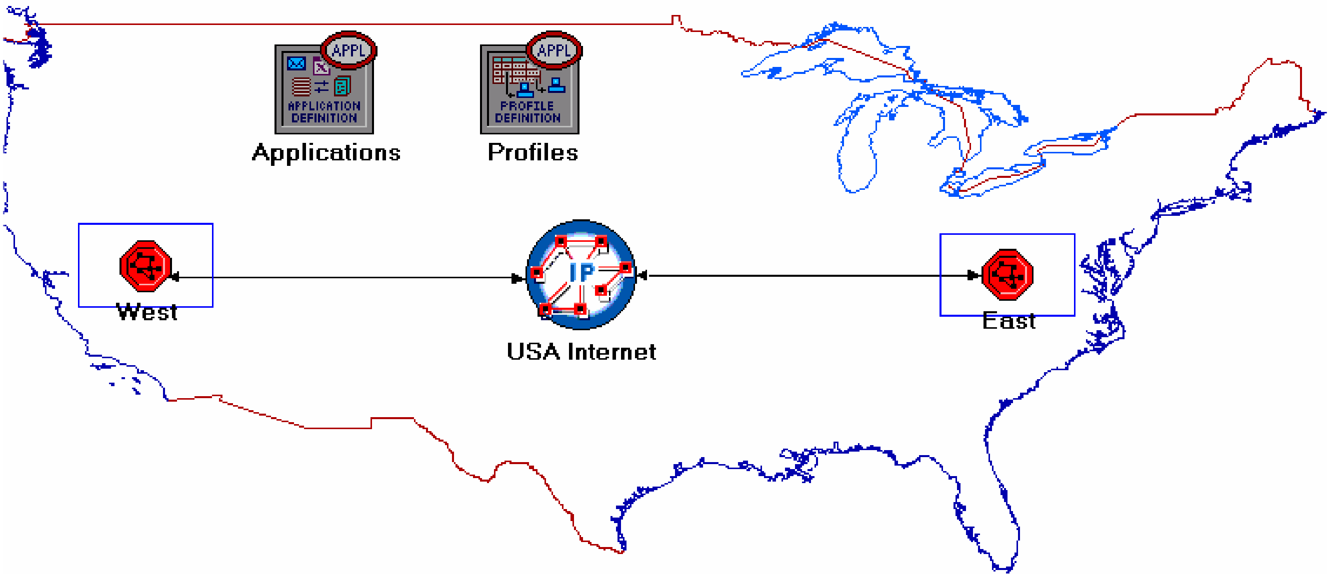
iii. Edit the **Application: Destination Preferences** attribute as follows:

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

5. Click OK three times and then save your project.
6. You have now completed the configuration of the East subnet. To go back to the project space, click the **Go to next higher level**  button.

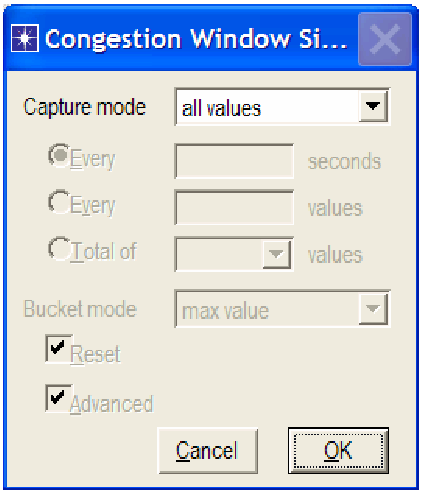
9.4.2.6. Connect the Subnets to the IP Cloud:

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.



9.4.3. 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:
3. TCP Connection ⇒ **Congestion Window Size** (bytes) and **Sent Segment Sequence Number**.
4. 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.



OPNET 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 10^{th} second. If the sample count is 10, every 10^{th} data points is recorded. All other data points are discarded.
- **Bucket** – collects all of the points over the time interval or sample count into a “data busket” and generates a result from each bucket. This is the default mode.

5. 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.
6. Click OK twice and then save your project.
7. Click the Go to next higher level  button.

9.4.4. 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 OK and then save your project.

9.4.5. Duplicate the Scenario

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

1. Select **Duplicate Scenario** from the **Scenarios** menu and give it the name **Drop_NoFast** ⇒ Click **OK**.
2. In the new scenario, right-click on the **IP Cloud** ⇒ **Edit Attributes** ⇒ Assign **0.05%** to the **Packet Discard Ratio** attribute.
3. Click **OK** and then save your project.
4. While you are still in the **Drop_NoFast** scenario, select **Duplicate Scenario** from the **Scenarios** menu and give it the name **Drop_Fast**.

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

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

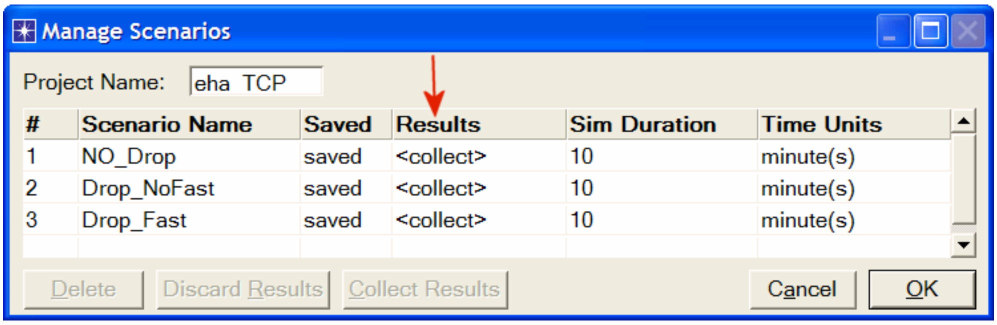
With **fast transmit**, TCP performs a retransmission of what appears to be the missing segment for a retransmission timer to expire. After fast retransmit sends what appears to be the missing segment, congestion advance but not slow start is performed. This is the **fast recovery** algorithm. The fast retransmit and fast recovery algorithms are usually implemented together (RFC 2001).

9.4.6. Run the Simulation

To run the simulation for the three scenarios simultaneously:

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

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



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

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

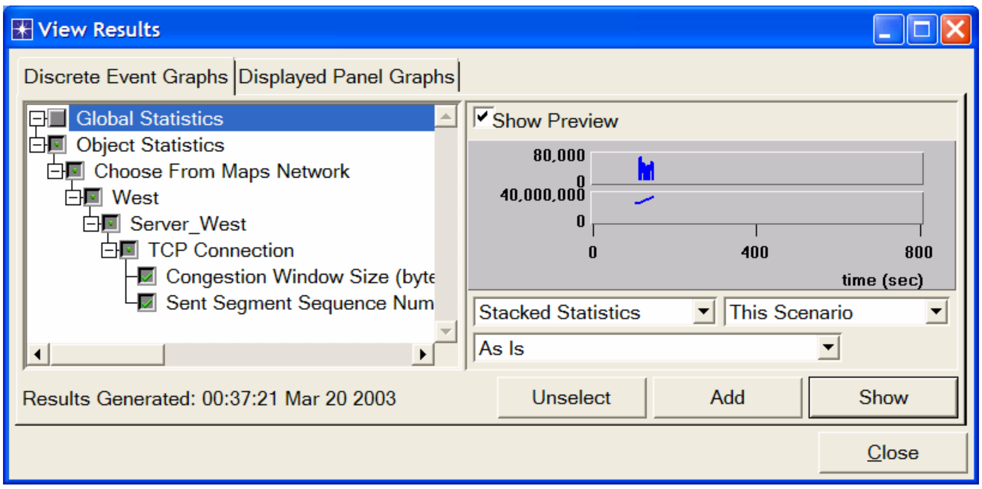
9.4.7. View the Results

To view and analyze the results.

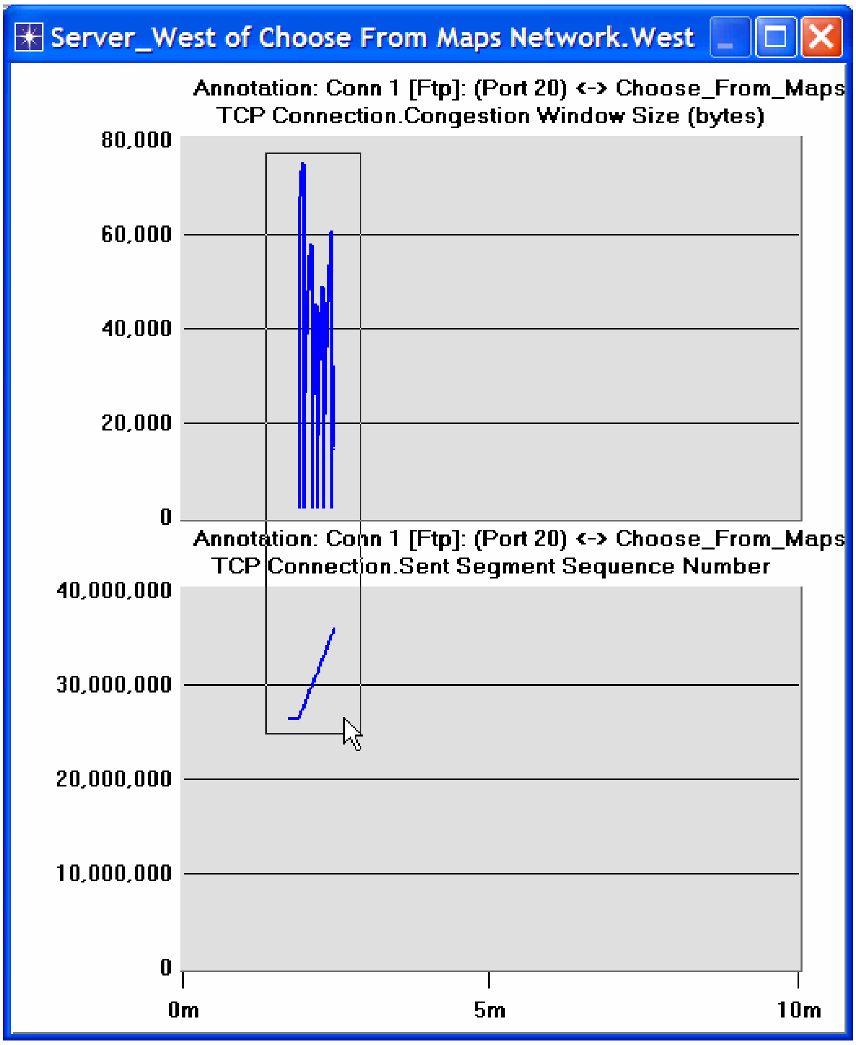
1. Switch to the **Drop_NoFast** scenario (the second one) and choose **View Results** from the **Results** menu.

2. Fully expand the **Object Statistics** hierarchy and select the following two results: **Congestion Window Size (bytes)** and **Sent Segment Sequence Number.**

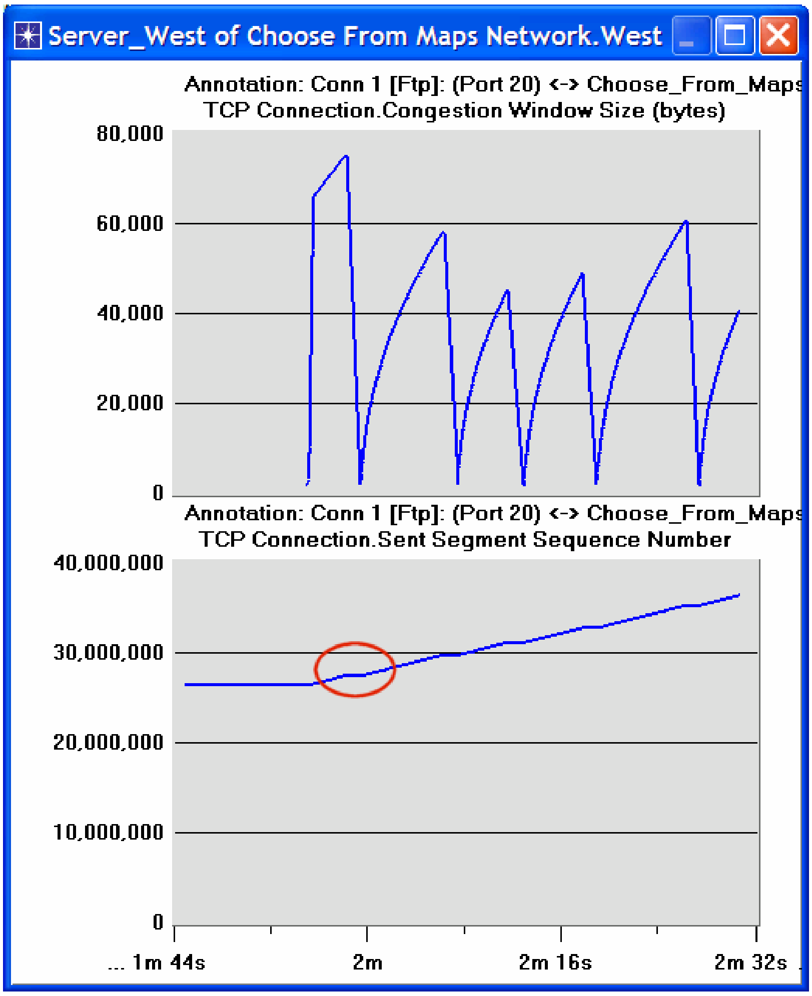
To switch to a scenario, choose **Switch to Scenario** from the **Scenarios** menu or just press **Ctrl+<scenario number>**



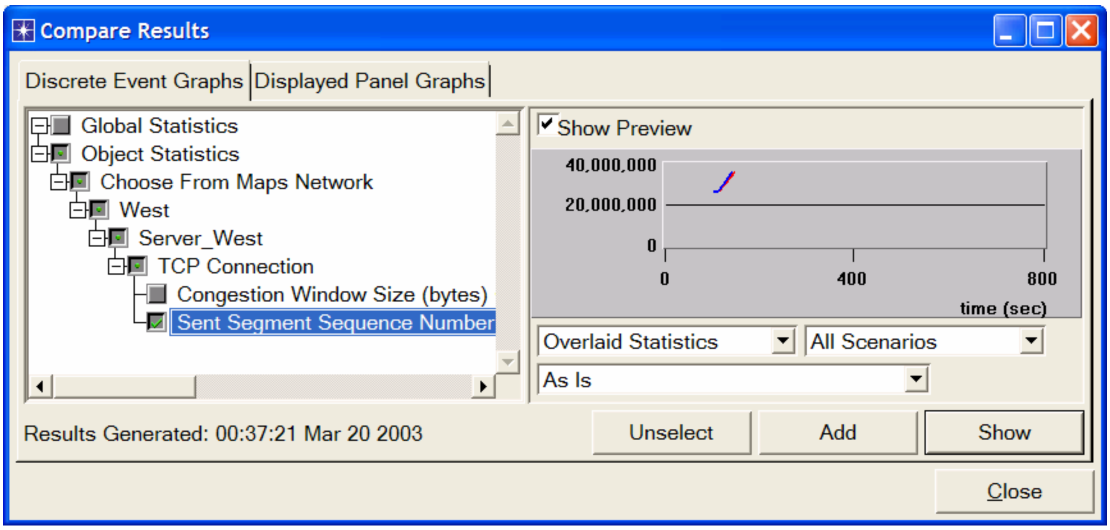
3. Click **Show**. The resulting graphs should resemble the ones below.



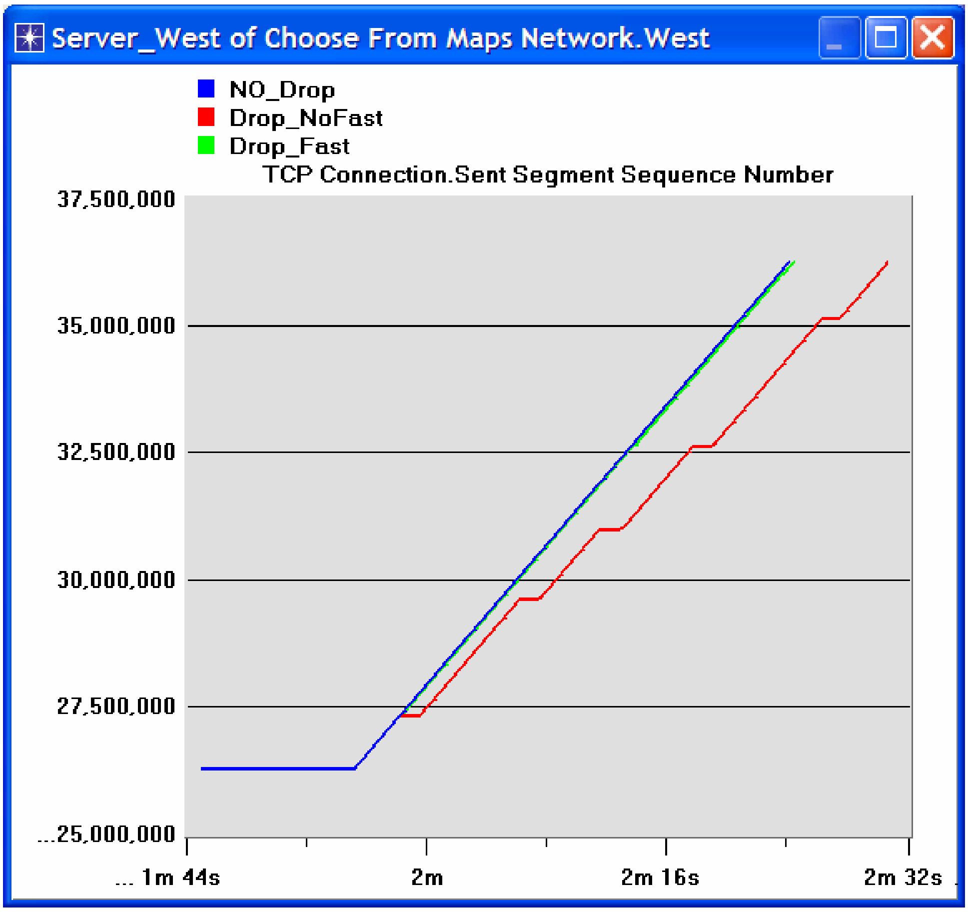
4. To zoom in on the details in the graph, click and drag your mouse to draw a rectangle, as shown above.
5. The graph should be redrawn to resemble the following one:



6. Notice the **Segment Sequence Number** is almost flat with every drop in the congestion window.
7. Close the View Results dialog box and select **Compare Results** from the **Result** menu.
8. Fully expand the **Object Statistics** hierarchy as shown and select the following result: **Sent Segment Sequence Number**.



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



9.5. *Further readings*

- OPNET TCP Model Description: From the **Protocols** menu, select **TCP** ⇒ Model Usage Guide.
- Transmission Control Protocol: IETF RFC number 793 (www.ietf.org/rfc.html).

9.6. *Exercises*

1) Why does the **Segment Sequence Number** remain unchanged (indicated by a horizontal line in the graphs) with every drop in the congestion window?
2) Analyze the graph that compares the **Segment Sequence** numbers of the three scenarios. Why does the **Drop_NoFast** scenario have the slowest growth in sequence numbers?
3) In the **Drop_NoFast** scenario, obtain the overlaid graph that compares **Sent Segment Sequence Number** with **Received Segment ACK Number** for **Server_West.** Explain the graph.

Hint:

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

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

scenario with the corresponding graph from the **Q4_Drop_Fast_Buffer** scenario.)

9.7. *Lab Report*

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

10. Laboratory - Queuing Disciplines (Order of Packet Transmission and Dropping)

10.1. *Objective*

The objective of this lab is to examine the effect of different queuing disciplines on packet delivery and delay for different services.

10.2. *Overview*

As part of the resource allocation mechanisms, each router must implement some queuing discipline that governs how packets are buffered while waiting to be transmitted. Various queuing disciplines can be used to control which packets get transmitted (bandwidth allocation) and which packets get dropped (buffer space). The queuing discipline also affects the latency experienced by a packet, by determining how long a packet waits to be transmitted. Examples of the common queuing disciplines are first-in-first-out (FIFO) queuing, priority queuing (PQ), and weighted-fair queuing (WFQ).

The idea of FIFO queuing is that the first packet that arrives at a router is the first packet to be transmitted. Given that the amount of buffer space at each router is finite, if a packet arrives and the queue (buffer space) is full, then the router discards (drops) that packet. This is done without regard to which flow the packet belongs to or how important the packet is.

PQ is a simple variation of the basic FIFO queuing. The idea is to mark each packet with a priority; the mark could be carried, for example, in the IP Type of Service (ToS) field. The routers then implement multiple FIFO queues, one for each priority class. Within each priority, packets are still managed in a FIFO manner. This queuing discipline allows high-priority packets to cut to the front of the line.

The idea of the fair queuing (FQ) discipline is to maintain a separate queue for each flow currently being handled by the router. The router then services these queues in a round-robin manner. WFQ allows a weight to be assigned to each flow (queue). This weight effectively controls the percentage of the link's bandwidth each flow will get. We could use ToS bits in the IP header to identify that weight.

In this lab you will set up a network that carries three applications: FTP, Video, and VoIP. You will study how the choice of the queuing discipline in the routers can affect the performance of the applications and the utilization of the network resources.

10.3. *Prelab Activities*

- Read section 6.2 from ***"Computer Networks: A Systems Approach"***, 4th ***Edition.***

  Go to ***www.net-seal.net/animations.php*** and play the following animations:
  - Switch Congestion.
  - IP Fragmentation.

10.4. *Procedure*

10.4.1. Create a New Project

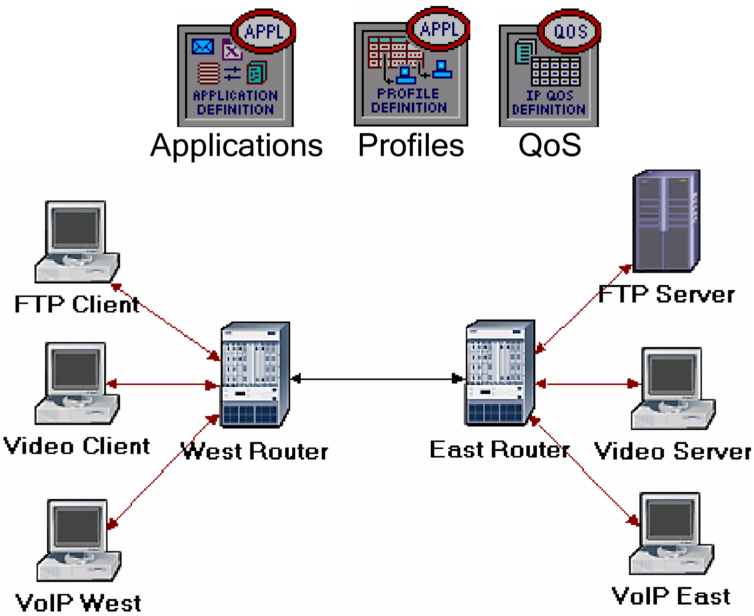
1. Start **OPNET IT Guru Academic Edition** ⇒ Choose **New** from the **File** menu.

2. Select **Project** and Click **OK** ⇒ Name the project **<your initials>_Queues**, and the scenario **FIFO** ⇒ Click **OK**.
3. In the *Startup Wizard: Initial Topology* dialog box, make sure that **Create Empty Scenario** is selected ⇒ Click **Next** ⇒ Select **Campus** from the *Network Scale* list ⇒ Click **Next** three times ⇒ Click **OK**.

10.4.2. Create and Configure the Network

10.4.2.1. Initialize the 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 **internet_toolbox** item is selected from the pull-down menu on the object palette.
2. Add to the project workspace the following objects from the palette: **Application Config**, **Profile Config**, **QoS Attribute Config**, five **ethernet_wkstn**, one **ethernet_server**, and two **ethernet4_slip8_gtwy** routers.
3. Connect both routers together with a bidirectional **PPP_DS1** link.
4. Connect the workstations and the server to the routers using bidirectional **10Base_T** links as shown.
5. Rename the objects you added as shown and then save your project.



The **QoS Attribute Config** node defines attribute configuration details for protocols supported at the IP layer. These specifications can be referenced by the individual nodes using symbolic names. It defines different queuing profiles such as FIFO, WFQ, priority queuing, custom queuing, MWRR, MDRR, and DWRR.

10.4.2.2. Configure the Applications:

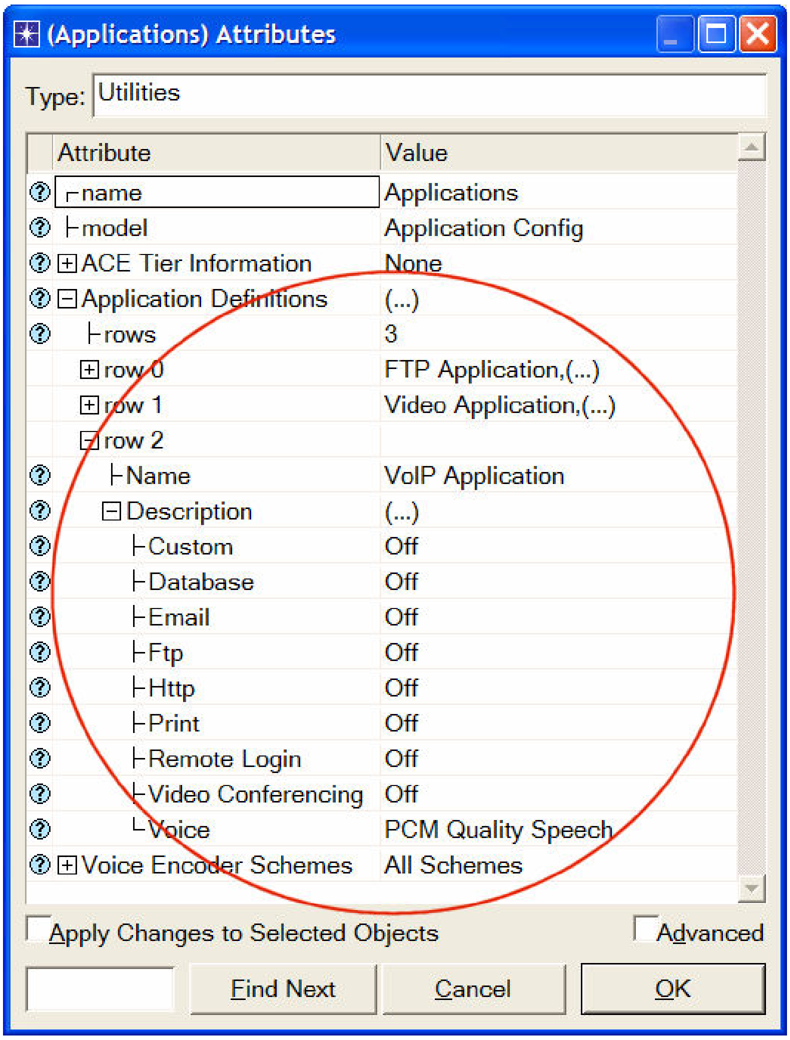
1. Right-click on the **Applications** node ⇒ **Edit Attributes** ⇒ Expand the **Application Definitions** hierarchy ⇒ Set **rows** to 3 ⇒ Name the rows: **FTP Application**, **Video Application**, and **VoIP Application**.

   i. Go to the **FTP Application** row ⇒ Expand the **Description** hierarchy ⇒ Assign **High Load** to **Ftp** ⇒ Click on the **High Load** value and choose **Edit** from the drop-down menu ⇒ Assign **Constant(10)** to **Inter-Request Time** ⇒ Assign **Constant(1000000)** to **File Size.** Keep the **Type of Service** (**ToS**) as **Best Effort (0)**.

ii. Go to the **Video Application** row ⇒ Expand the **Description** hierarchy ⇒ Assign **Low Resolution Video** to **Video Conferencing** ⇒ Click on the **Low Resolution Video** value and choose **Edit** ⇒ Edit the value of the **Type of Service** field (the **Configure TOS/DSCP** window appears) ⇒ From the drop-down menu, assign **Streaming Multimedia (4)** to **ToS** ⇒ Click **OK** twice.

iii. Go to the **VoIP Application** row ⇒ Expand the **Description** hierarchy ⇒ Assign **PCM Quality Speech** to **Voice**. If you edit it, you can see that the ToS assigned to it is **Interactive Voice (6)**.

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



Type of Service (ToS) is assigned to the IP packets. It represents a session attribute that allows packets to be provided the appropriate service in the IP queues.

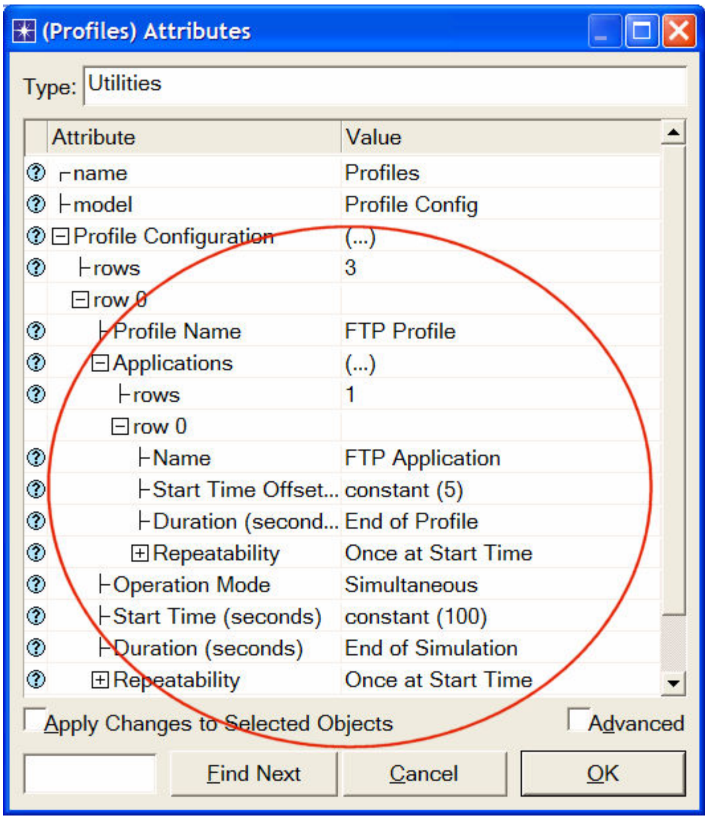
Best-effort delivery means that delivery of a packet is attempted but is not guaranteed.

PCM (Pulse Code Modulation) is a procedure used to digitize speech before transmitting it over the network.

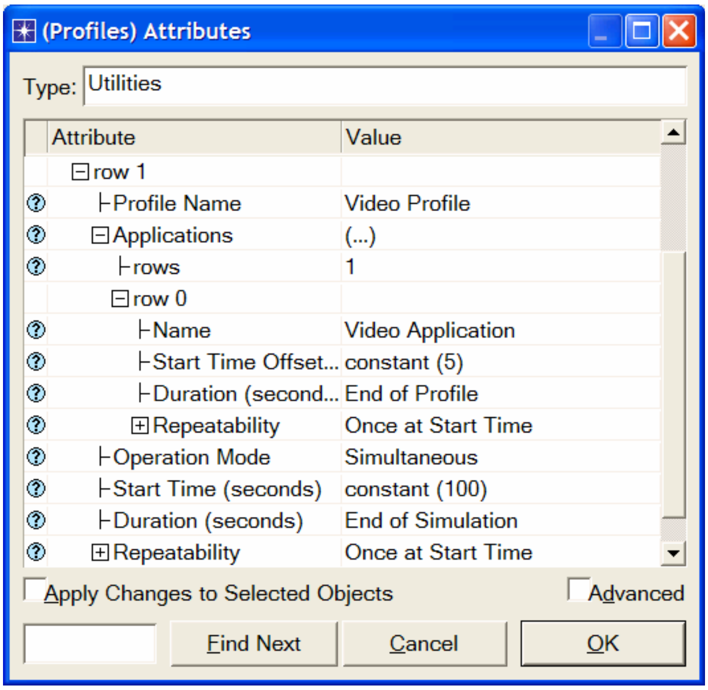
10.4.2.3. Configure the Profiles:

1. Right-click on the **Profiles** node ⇒ **Edit Attributes** ⇒ Expand the **Profile Configuration** hierarchy ⇒ Set **rows** to **3**.

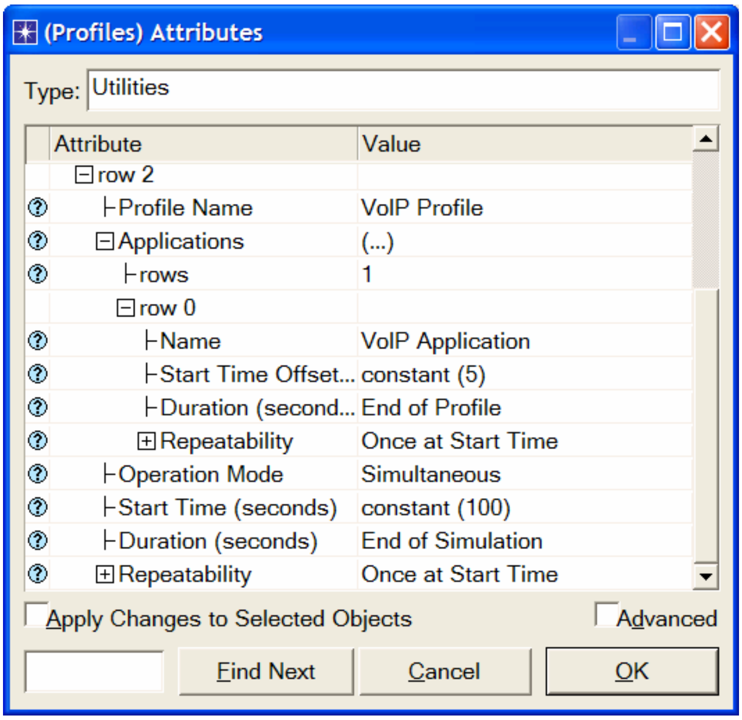
i. Name and set the attributes of **row 0** as shown:



ii. Name and set the attributes of row 1 as shown:



iii. Name and set the attributes of row 2 as shown:



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

10.4.2.4. Configure the Queues:

We will keep the default queuing profiles that are defined in our **Queues** object. It is recommended that you check out the configuration of the FIFO, PQ, and WFQ profiles.

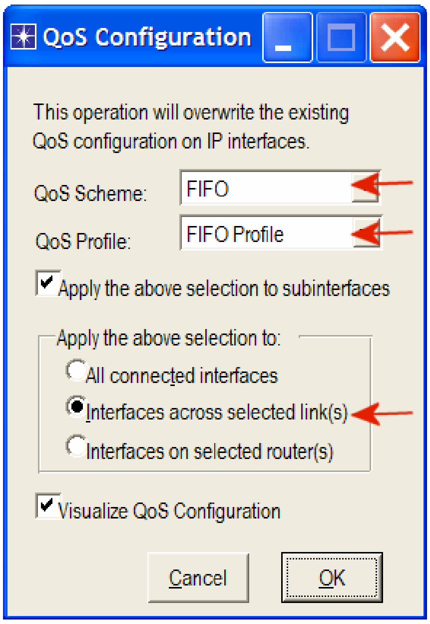
10.4.2.5. Configure the Workstations and Servers:

1. Right-click on the **FTP Client** ⇒ **Edit Attributes** ⇒ Expand the **Application: Supported Profiles** hierarchy ⇒ Set **rows** to **1** ⇒ Set **Profile Name** to **FTP Profile** ⇒ Click **OK**.
2. Right-click on the **Video Client** ⇒ **Edit Attributes** ⇒ Expand the **Application: Supported Profiles** hierarchy ⇒ Set **rows** to **1** ⇒ Set **Profile Name** to **Video Profile** ⇒ Click **OK**.
3. Right-click on the **VoIP West** ⇒ **Edit Attributes**.
   i. Expand the **Application: Supported Profiles** hierarchy ⇒ Set **rows** to **1** ⇒ Set Profile Name to **VoIP Profile**.
   ii. Edit the **Application: Supported Services** value ⇒ Set **rows** to **1** ⇒ Set **Service Name** to **VoIP Application** ⇒ Click **OK** twice.
4. Right-click on the **VoIP East** ⇒ **Edit Attributes.**
   i. Expand the **Application: Supported Profiles** hierarchy ⇒ Set **rows** to **1** ⇒ Set **Profile Name** to **VoIP Profile**.
   ii. Edit the **Application: Supported Services** value ⇒ Set **rows** to **1** ⇒ Set **Service Name** to **VoIP Application** ⇒ Click **OK** twice.
5. Right-click on the **FTP Server** ⇒ **Edit Attributes** ⇒ Edit the **Application: Supported Services** value ⇒ Set **rows** to **1** ⇒ Set **Service Name** to **FTP Application** ⇒ Click **OK** twice.

6. Right-click on the **Video Server** ⇒ **Edit Attributes** ⇒ Edit the **Application: Supported Services** value ⇒ Set **rows** to **1** ⇒ Set **Service Name** to **Video** ⇒ Click **OK** twice.
7. Save your project.

10.4.2.6. Configure the Routers:

1. Click on the link connecting the **East** and **West** routers to select it. ⇒ From the **Protocols** menu choose **IP** → **QoS** → **Configure QoS**.
2. Make sure the selected items are as shown in the following *QoS Configuration* dialog box ⇒ Click **OK**.



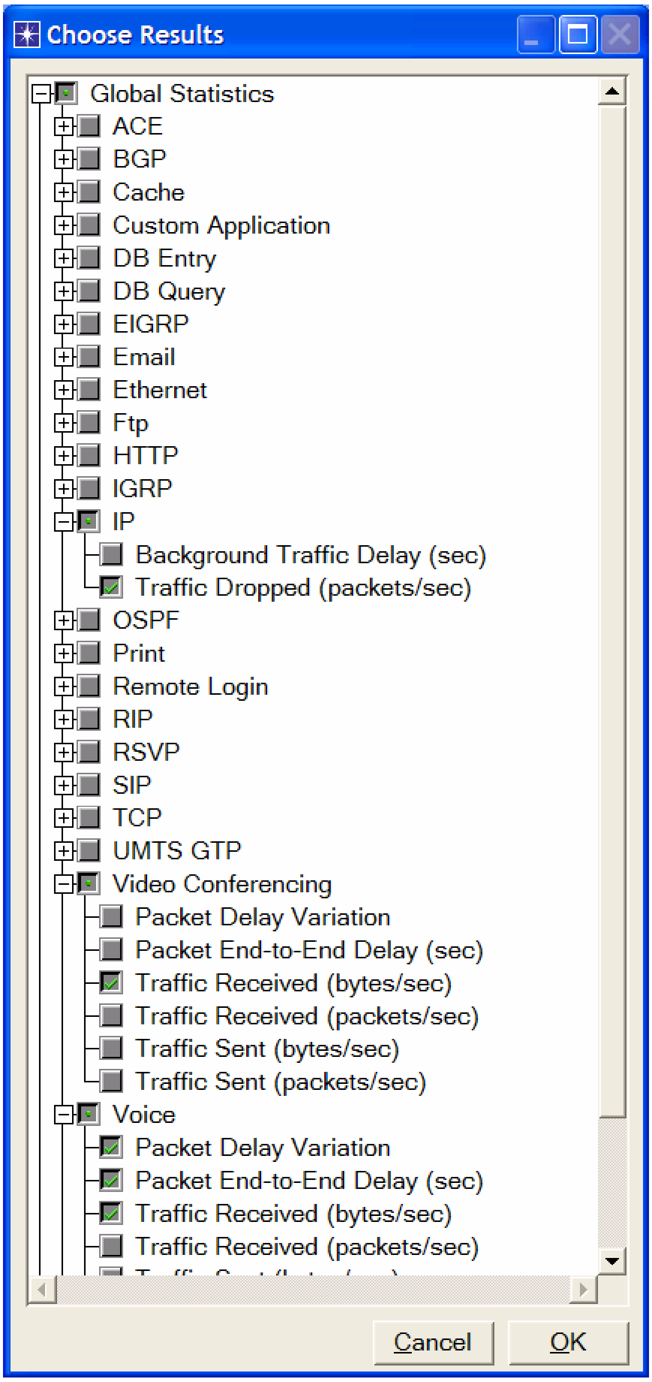
Note: Since the **Visualize QoS Configuration** radio button is checked, the link is colored based on the QoS scheme used (blue for FIFO).

3. Save your project.

10.4.3. Choose the Statistics

To test the performance of the applications defined in the network, 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, select the following global statistics:



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

Traffic Dropped. The number of IP diagrams dropped by all nodes in the network across all IP interfaces. The reason for dropping an IP datagram can be any one of the following:

- Insufficient space in the queue
- Maximum number of bops exceeded by an IP datagram.
- On nonrouting nodes, a local router interface was not found to be used as the next hop.
- On routing nodes, the route table lookup failed to yield a route to the destination.

10.4.4. 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 **150 seconds**.

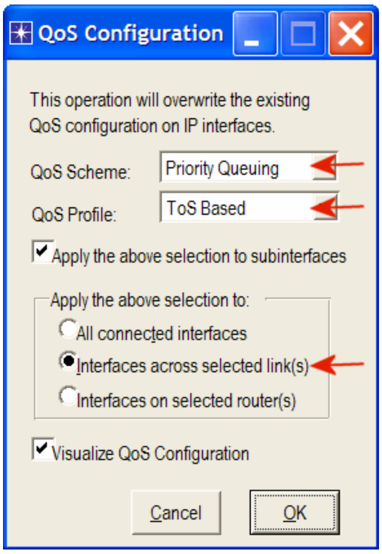
3. Click **OK** and then save your project.

10.4.5. Duplicate the Scenario

In the network we just created, we used the FIFO queuing discipline in the routers. To analyze the effect of different queuing disciplines, we will create two more scenarios to test the **PQ** and **WFQ** disciplines.

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

1. Click on the link connecting the **East** and **West** routers to select it ⇒ From the **Protocols** menu choose **IP** → **QoS** → **Configure QoS**.
2. Make sure the selected items are as shown in the following *QoS Configuration* dialog box ⇒ Click **OK**.

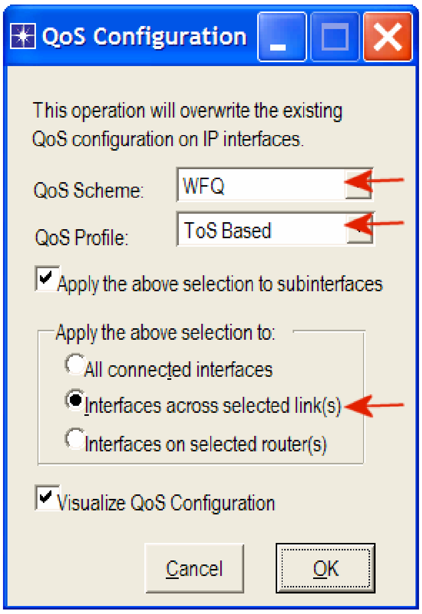


Note: Since the **Visualize QoS Configuration** radio button is checked, the link is colored based on the QoS scheme used (orange for priority queuing).

3. Save your project.

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

1. Click on the link connecting the **East** and **West** routers to select it ⇒ From the **Protocols** menu choose **IP** → **QoS** → **Configure QoS**.
2. Make sure the selected items are as shown in the following *QoS Configuration* dialog box ⇒ Click **OK**.



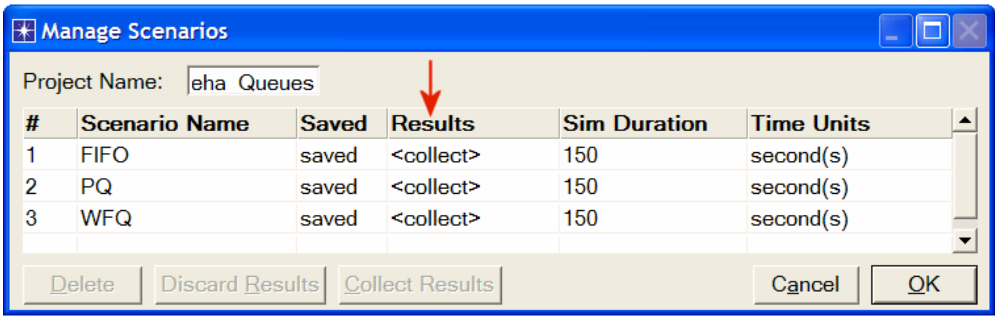
Note. Since the **Visualize QoS Configuration** radio button is checked the link is colored based on the **QoS** scheme used (green for WFQ).

3. Save your project.

10.4.6. Run the Simulation

To run the simulation for the three scenarios simultaneously:

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



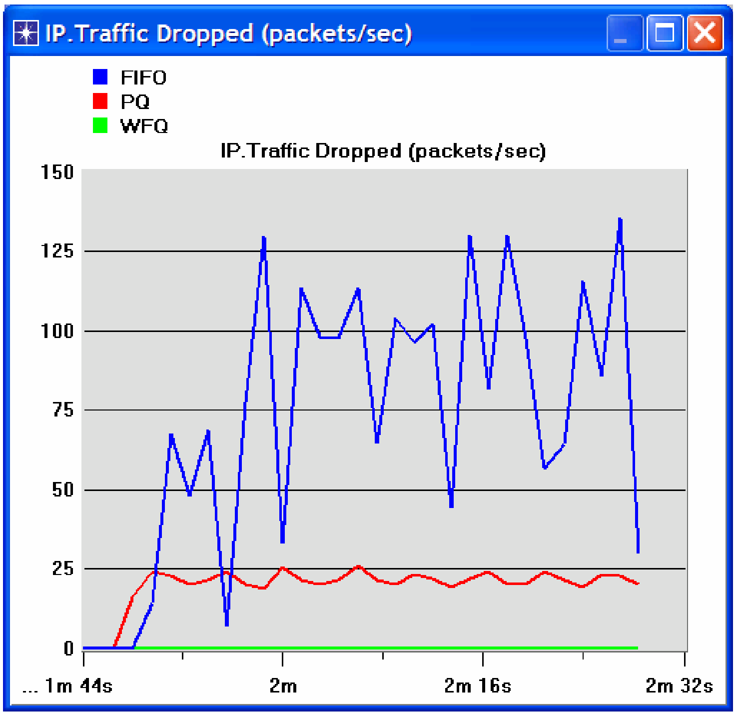
3. Click **OK** to run the three simulations. Depending on the speed of your processor, this may take several minutes to complete.
4. After the simulation completes the three runs, one for each scenario, click **Close**.
5. Save your project.

Note: Actual results will vary slightly based on the actual node positioning in the project.

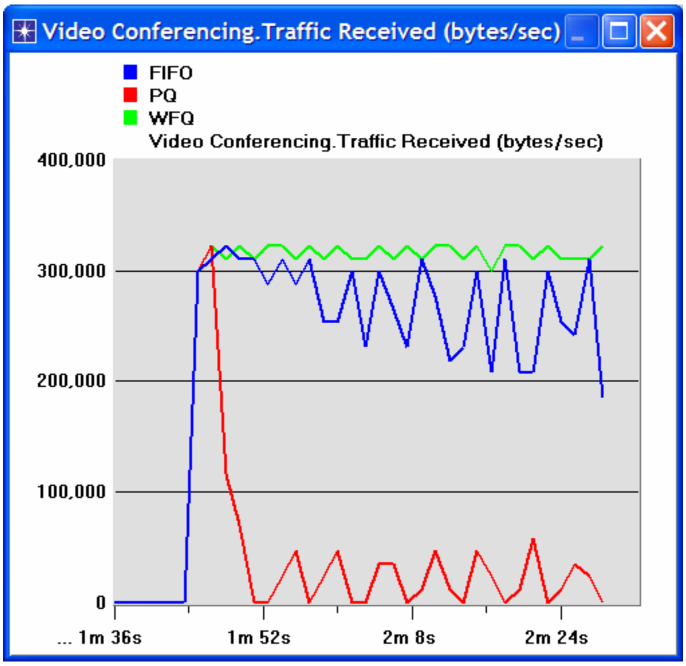
10.4.7. View the Results

To view and analyze the results:

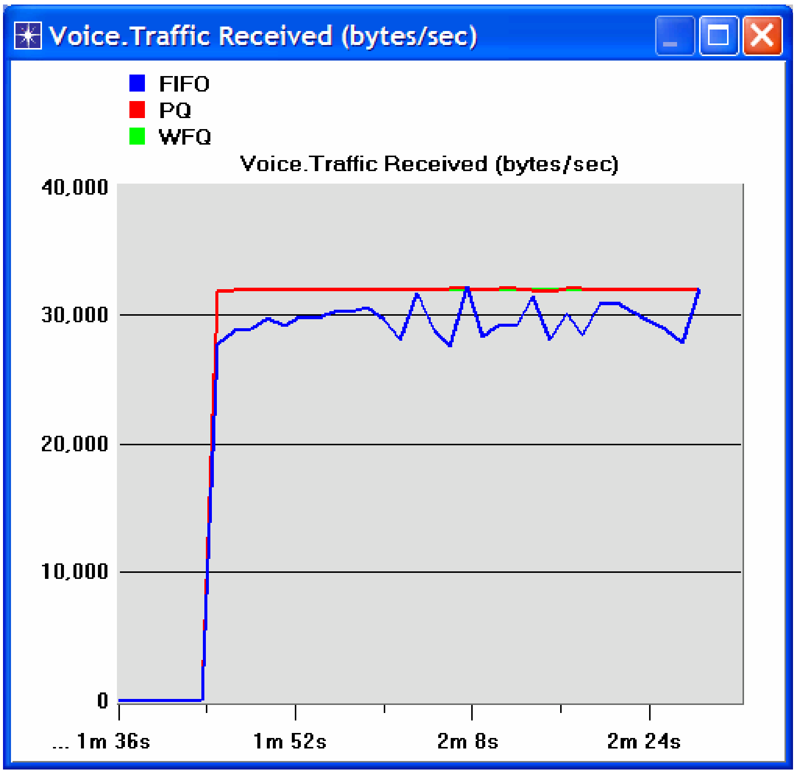
1. Select **Compare Results** from the **Results** menu.
2. Select the IP **Traffic Dropped** statistic and click **Show.** The resulting graph should resemble the one below. *Note:* The shown graph is the result of zooming into the region of interest on the original graph.



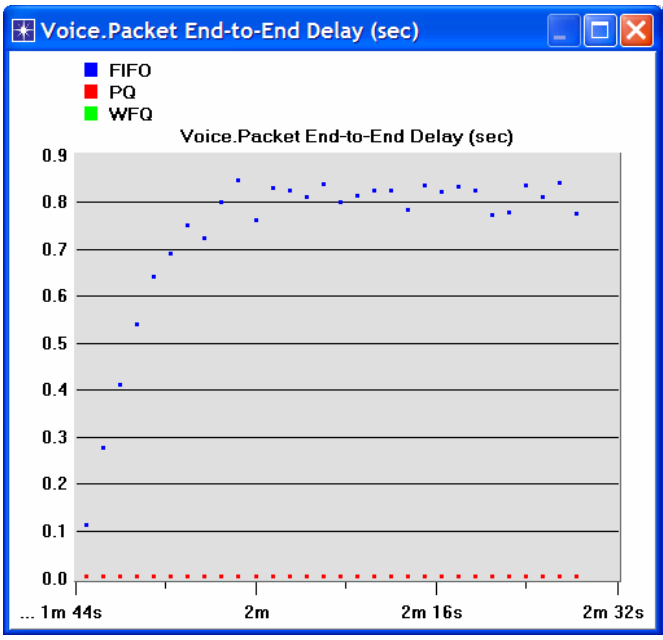
3. Create the graph for **Video Conferencing Traffic Received:**

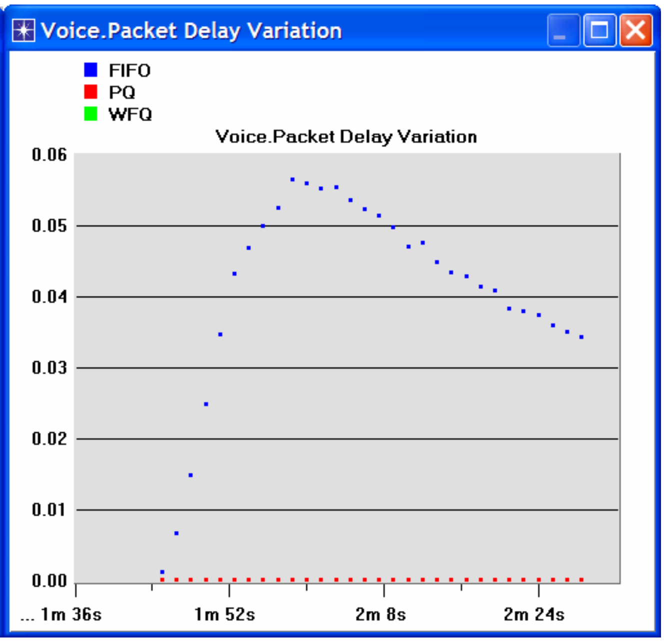


4. Create the graph for **Voice Traffic Received**:



5. Create graphs for **Voice Packet End-to-end Delay** and **Voice Packet Delay Variation** (Note: the trace for **WFQ** is not shown on the following graphs because it is overlapped by the trace of **PQ**.)





10.5. *Further readings*

- The Differentiated Services Field: IETF RFC number 2474 (www.ietf.org/rfc.html).

10.6. *Exercises*

1) Analyze the graphs we obtained and verify the overlap of the **Voice Packet End-to-end Delay** and **Voice Packet Delay Variation** graphs. Compare the three queuing disciplines and explain their effect on the performance of the three applications.

2) In the implemented project, edit the **Queues** object and check the profiles assigned to the **FIFO**, **PQ**, and **WFQ** disciplines. For each profile answer the following questions:

   a. How many queues are associated with each discipline?

   b. In this lab, we used **ToS** to identify the priority and weight for the **PQ** and **WFQ** disciplines respectively. What are the other parameters that can be used to identify the priority and weight?

   c. In **PQ,** how are queues configured to serve different **ToS** values?

   d. In **WFQ,** how are queues configured to serve different **ToS** values?

3) For all scenarios, choose the "**queuing delay 🡐**" statistic for the link that connects **East Router** and **West Router**. Rerun the simulation and generate the graph that compares that **queuing delay** for all queuing disciplines (scenarios). Analyze this graph.

Hint:

- The "**queuing delay 🡐**" statistic is under the point-to-point hierarchy.

10.7. *Lab Report*

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

11. Laboratory - RSVP: Resource Reservation Protocol (Providing QoS by Reserving Resources in the Network)

11.1. *Objective*

The objective of this lab is to study the Resource Reservation Protocol (RSVP) as a part of the Integrated Services approach to providing Quality of Service (QoS) to individual applications or flows.

11.2. *Overview*

For many years, packet-switched networks have offered the promise of supporting multimedia applications, that is, those that combine audio, video, and data. Audio and video applications are examples of *real-time* applications. In the best-effort model, the network tries to deliver your data but makes no promises and leaves the "cleanup operation" to the edges. This model is not sufficient for real-time applications. What we need is a new service model - one in which applications that need better assurances can request such service from the network. The network may then respond by providing an assurance that it will do better or perhaps by saying that it cannot promise anything better at the moment. A network that can provide different levels of service is often said to support QoS.

Two approaches have been developed to provide a range of QoS: Integrated Services and Differentiated Services. The Resource Reservation Protocol follows the Integrated Services approach, whereby QoS is provided to individual applications or flows. The Differentiated Services approach provides QoS to large classes of data or aggregated traffic.

While connection-oriented networks have always needed some sort of setup protocol to establish the necessary virtual circuit state in the routers, connectionless networks like the Internet have had no such protocols. One of the key assumptions underlying RSVP is that it should not detract from the robustness that we find in the Internet. Therefore, RSVP uses the idea of *soft state* in the routers. Soft state - in contrast to the *hard state* found in connection-oriented networks–does not need to be explicitly deleted when it is no longer needed instead, it times out after some fairly short period if it is not periodically refreshed. RSVP adopts the *receiver-oriented* approach - the receivers keep track of their own resource requirements, and they periodically send refresh messages to keep the soft state in place.

In this tab you will set up a network that carries real-time applications and that utilizes RSVP to provide QoS to one of these applications. You will study how RSVP contributes to the performance of the application that makes use of it.

11.3. *Prelab Activities*

- Read section 6.5 from ***"Computer Networks: A Systems Approach"***, 4th ***Edition.***

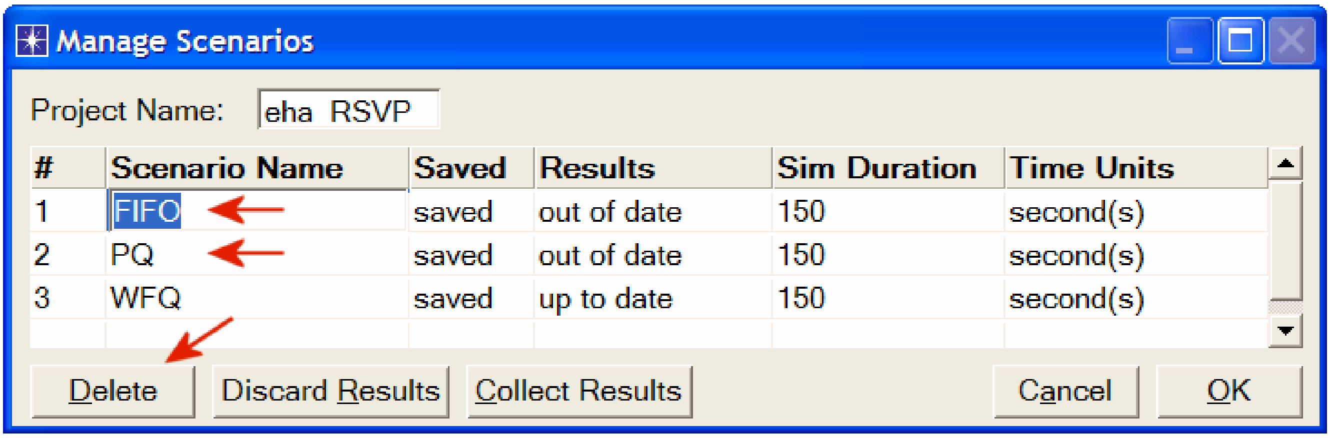
  Go to ***www.net-seal.net/animations.php*** and play the following animation:
  - TCP Flow Control.

11.4. *Procedure*

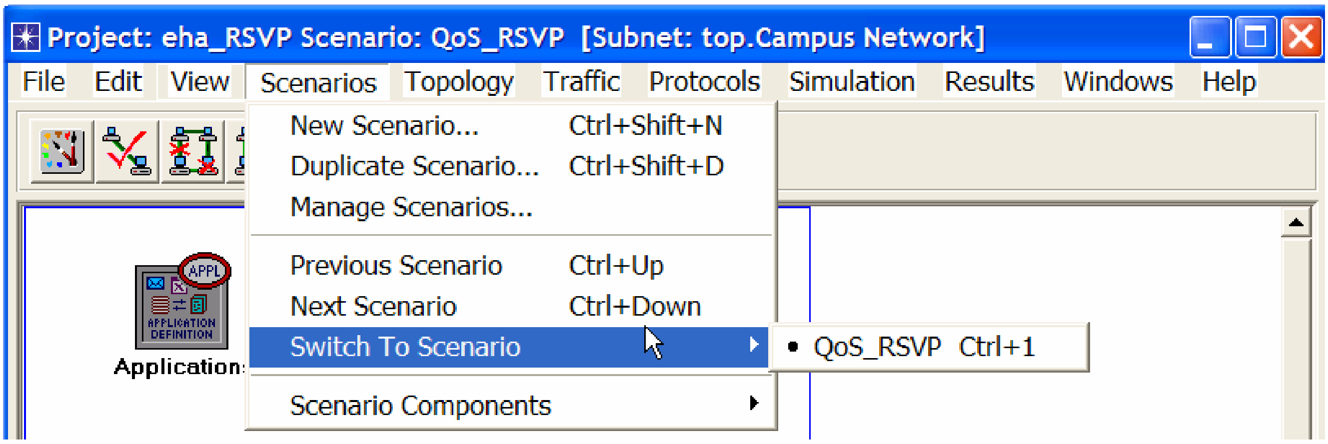
11.4.1. Create the Project

1. Start **OPNET IT Guru Academic Edition** ⇒ Choose **Open** from the **File** menu.

2. Select the project you created in Lab 9: **<your initials>_Queues** ⇒ Click **OK**.
3. From the **File** menu, choose **Save As** ⇒ Rename the project to **<your initiate>_RSVP** ⇒ Click **OK**.
4. From the **Scenarios** menu, choose **Manage Scenarios** ⇒ Click on **FIFO** ⇒ Click **Delete** ⇒ Click on **PQ** ⇒ Click **Delete**.



5. Click on **WFQ** and rename it to **QoS_RSVP** ⇒ Click **OK**.
6. Make sure that you have only the **QoS_RSVP** scenario in your project. The following figure shows one way to check for the available scenarios in the project.



7. Save your project.

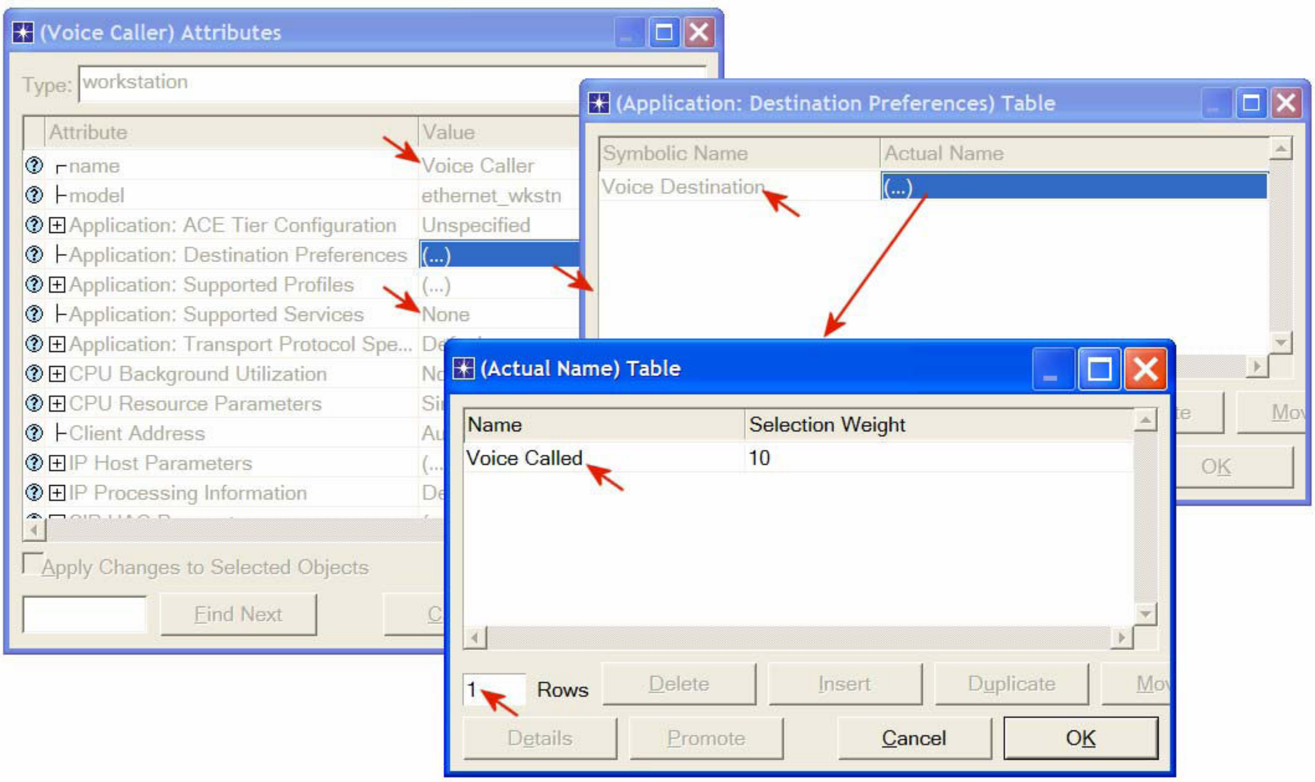
> The idea of the **FQ** (fair queuing) discipline is to maintain a separate queue for each flow currently being handled by the router. The router then service these queue in a round robin manner.
>
> **WFQ** allows a weight to be assigned to each flow (queue). This weight effectively controls the percentage of the link's bandwidth each flow will get. We could use the ToS (Type of Service) field in the IP header to identify that weight.

11.4.2. Configure the Network

11.4.2.1. Add More VoIP Nodes:

In this project we will set up the two VoIP nodes so that one will always be the *Caller* party and the other will be the *Called* party. In addition, we will add two new VoIP *Caller* and *Called* nodes. These new nodes will utilize RSVP to reserve their required resources through the network.

1. Right-click on the **VoIP East** node ⇒ **Edit Attributes.** ⇒ Rename the node to **Voice Called** ⇒ Assign **None** to the **Application: Supported Profiles** attribute ⇒ Assign **Voice Called** to the **Client Address** attribute ⇒ Click **OK**.
2. Right-click on the **VoIP West** node ⇒ **Edit Attributes**.
   i. Rename the node to **Voice Caller**.
   ii. Assign **None** to the **Application: Supported Services** attribute.
   iii. Edit the value of the **Application: Destination Preferences** attribute ⇒ Set **Rows** to **1** ⇒ Assign **Voice Destination** to the **Symbolic Name** of the new row ⇒ Edit the **Actual Name** attribute ⇒ Set **Rows** to **1** ⇒ Assign **Voice Called** to the **Name** attribute of the new row as shown.
   iv. Click **OK** three times.



3. Click on the **Voice Called** node to select it ⇒ From the **Edit** menu, select **Copy** ⇒ From the **Edit** menu, select **Paste** (alternatively, use the standard keyboard shortcuts, **Ctrl-C** and **Ctrl-V**).
   i. Locate the new node somewhere below the **Voice Called** node on the screen ⇒ Connect the new node to the **East Router** using a **10BaseT** link.
   ii. Right-click on the new node ⇒ **Edit Attributes**.
   iii. Click on the **ethernet_wkstn** value of the **model** attribute ⇒ Select **Edit** ⇒ Select the **ethernet_wkstn_adv** model.
   iv. Rename it to **Voice_RSVP Called** ⇒ Assign **Voice_RSVP Called** to its **Client Address** attribute.
   v. Click **OK**.
4. Copy and paste the **Voice Caller** node.
   i. Locate the new node somewhere below the **Voice Caller** node ⇒ Connect the new node to the **West Router** using a **10BaseT** link.

ii. Right-click on the new node ⇒ **Edit Attributes.**

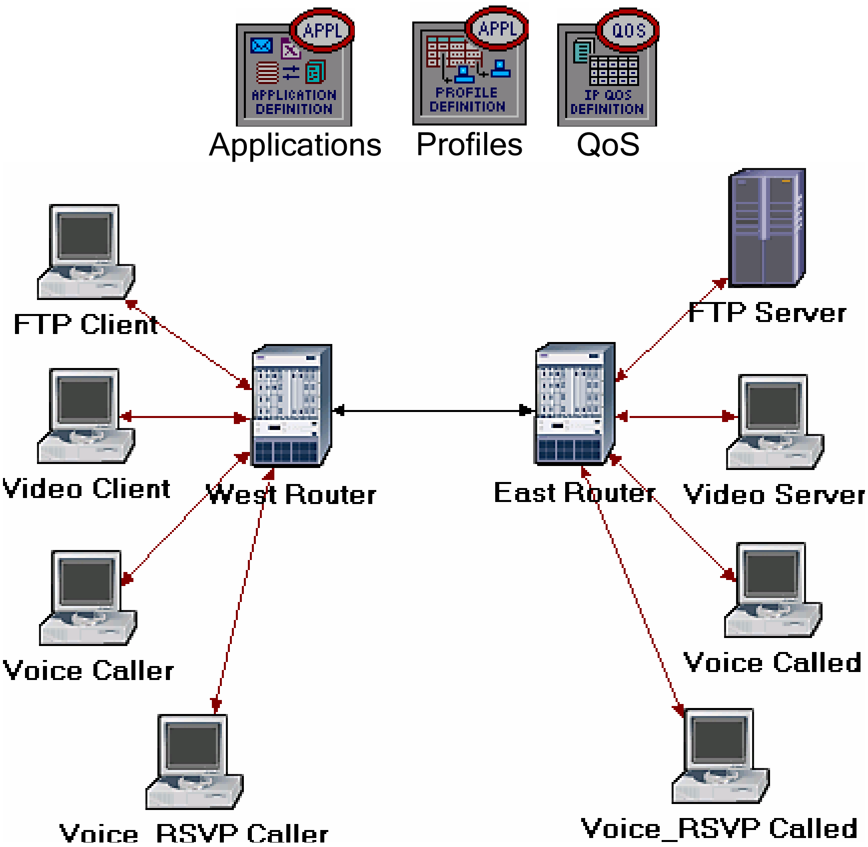
iii. Click on the **ethernet_wkstn** value of the **model** attribute ⇒ Select **Edit** ⇒ Select the **ethernet_wkstn_adv** model.

iv. Rename it to **Voice_RSVP Caller**.

v. Edit the **Application: Destination Preferences** attribute ⇒ Open the **Actual Name** table by clicking in the value field of **Actual Name** ⇒ Assign **Voice_RSVP Called** to the **Name** attribute (this is to replace the current value, which is **Voice Called**).

vi. Click **OK** three times.

5. Rename the **Queues** node in the project to **QoS**. Your project should look like the following diagram.
6. Save your project.



11.4.2.2. Define the Data Flow:

Here, we will define the data flow characteristics of the voice traffic in the network. The sender's RSVP module periodically sends RSVP Path messages, that uses the data flow characteristics to describe the traffic generated by the sender. When the receiver's RSVP module receives the Path message, the receiver host application checks the characteristics of the requested data flow and decides if resources should be reserved. Once a decision is made to request network resource reservation, the host application sends a request to the local RSVP module to assist in the reservation setup. The receiver's RSVP module then carries the request as Resv messages to all nodes along the reverse data path to the sender.

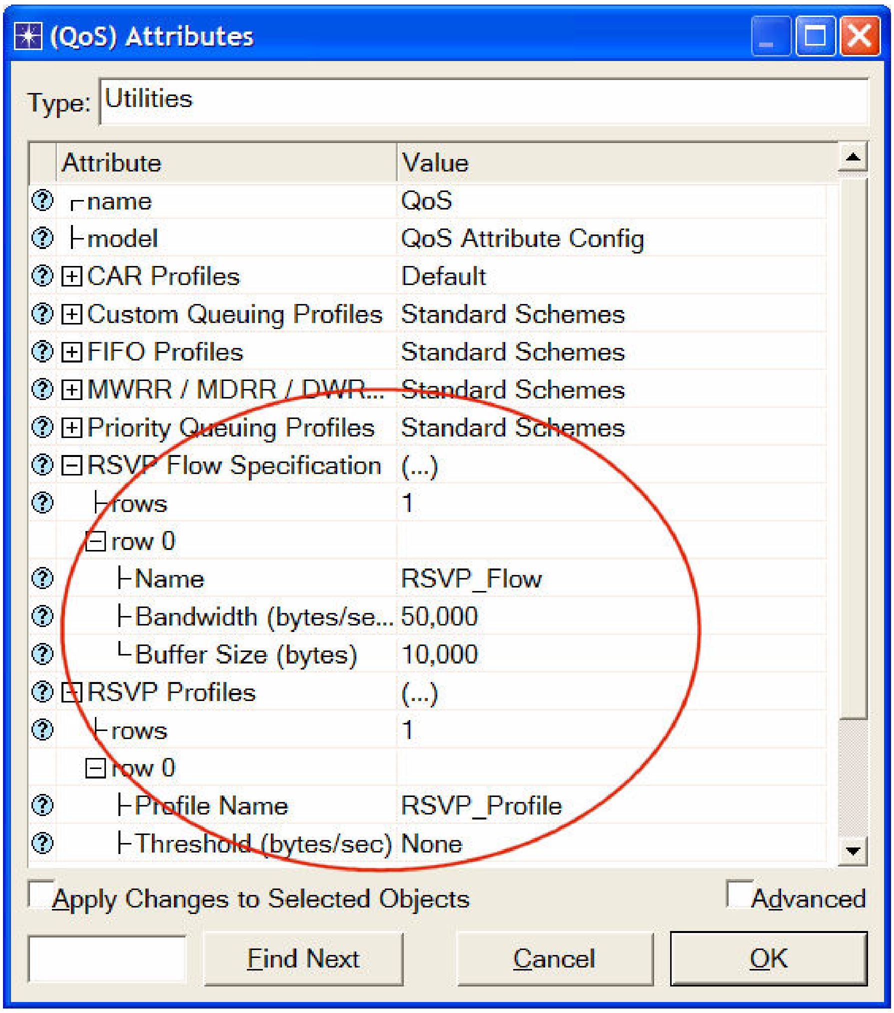
The flow is defined by its required bandwidth and buffer size. Bandwidth is set to be the *token bucket rate* in the flow specification of the Path and Resv messages. The buffer size represents the amount of the application "bursty" data to be buffered. It specifies the *token bucket size* that will be set in the Path or Resv messages for the session.

2. Right-click on the **QoS** node ⇒ **Edit Attributes.**

   i. Expand the **RSVP Flow Specification** hierarchy and its **row 0** hierarchy ⇒ Set **Name** to **RSVP_Flow** ⇒ Assign **50,000** to the **Bandwidth (bytes/sec)** attribute ⇒ Assign **10,000** to the **Buffer Size (bytes)** attribute.

   ii. Expand the **RSVP Profiles** hierarchy and its **row 0** hierarchy ⇒ Set **Profile Name** to **RSVP_Profile**.

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

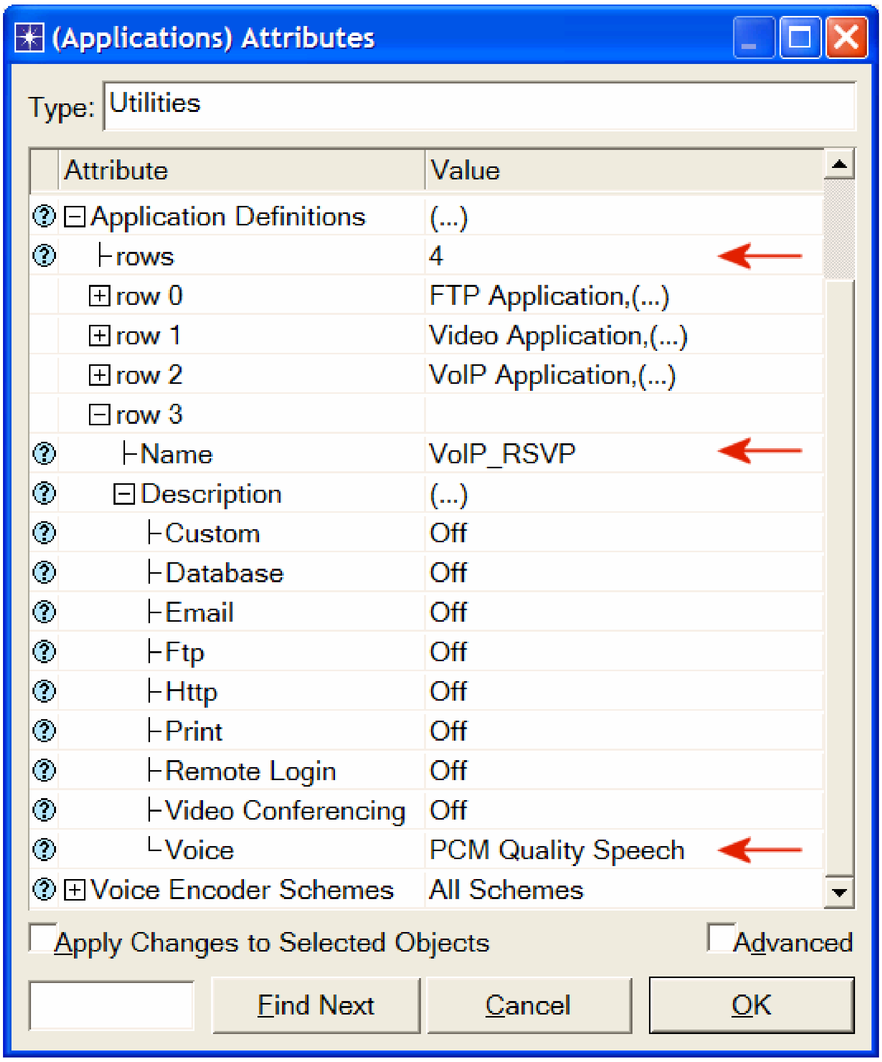


11.4.2.3. Configure the Application:

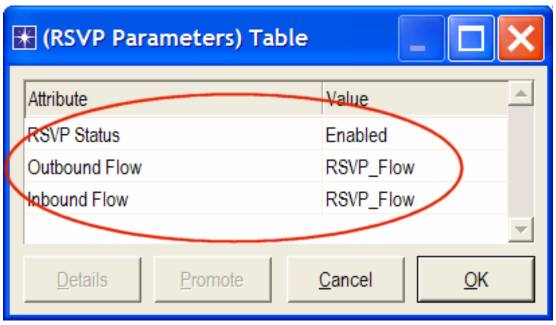
Here we will create a VoIP application that utilizes the RSVP flow specifications we configured.

1. Right-click on the **Applications** node ⇒ **Edit Attributes** ⇒ Expand the **Application Definitions** hierarchy ⇒ Set **rows** to **4** (to add a fourth row to the **Application Definitions** attribute).

   i. Name and set the attributes of row 3 as shown:



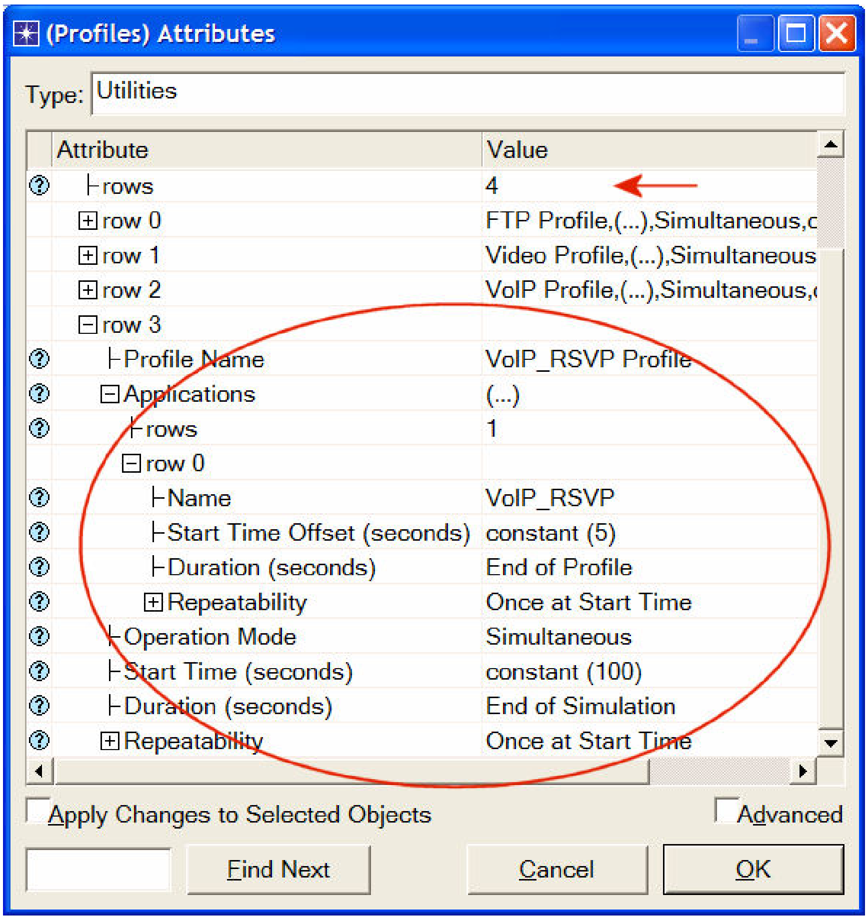
ii. Click on the **PCM Quality Speech** value (shown above) ⇒ Select **Edit** ⇒ Edit the value of the **RSVP Parameters** attribute ⇒ Assign the following values (recall that we defined the **RSVP_Flow** in the QoS node) ⇒ Click **OK** three times.



Note that the characteristics of the **Outbound Flow** are carried in the Path messages to be sent from sender to receiver, and the characteristics of the **Inbound Flow** parameters are carried in the Resv messages to be sent from the receiver to the sender.

11.4.2.4. Configure the Profile:

1. Right-click on the **Profiles** node ⇒ **Edit Attributes** ⇒ Expand the **Profile Configuration** hierarchy ⇒ Set **rows** to **4** (to add a fourth row to the **Profile Configuration** attribute) ⇒ Name and set the attributes of row 3 as shown:

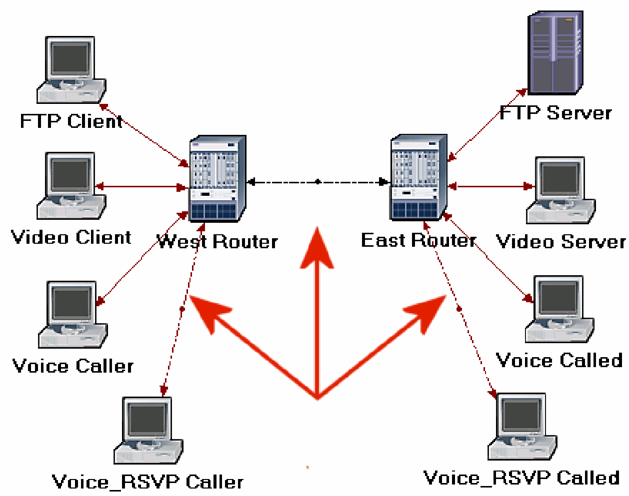


2. Click **OK** and then save your project.

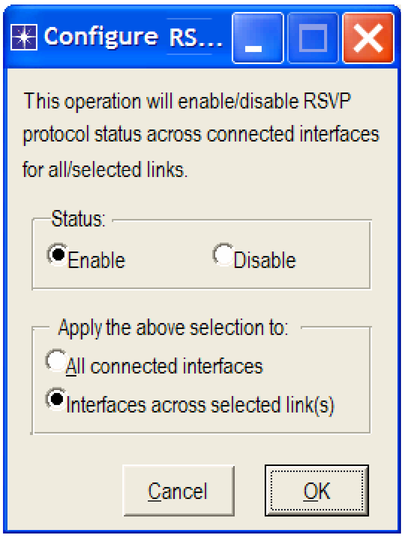
11.4.2.5. Configure the Interfaces:

OPNET IT Guru supports RSVP on a per-interface basis; RSVP can be enabled or disabled for each node's interface.

1. Simultaneously select (shift + left-click) the following three links:



2. From the **Protocols** menu, select **RSVP** ⇒ Select **Configure Interface Status** ⇒ Make the selections shown below in the configuration dialog box ⇒ Click **OK** and then save your project.



The above process enables RSVP on all interfaces along the path between the two Voice parties that need to utilize RSVP.

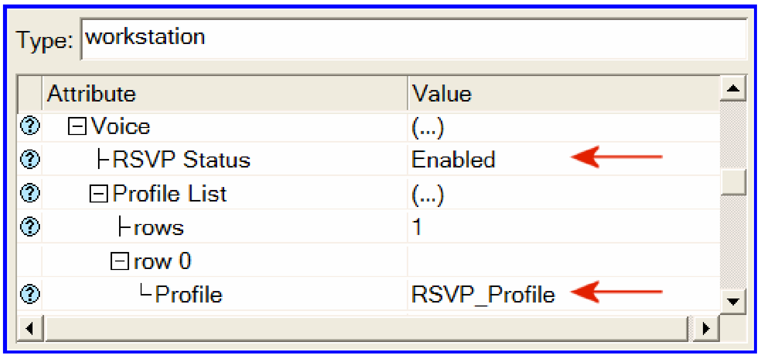
11.4.2.6. Configure the Hosts and Routers:

In OPNET IT Guru, the RSVP process runs only in IP-enabled nodes. The advanced versions (***_adv**) of those node models must be used, as we did already, to configure RSVP-related parameters. In addition, the RSVP model in OPNET IT Guru requires either WFQ or custom queuing schemes.

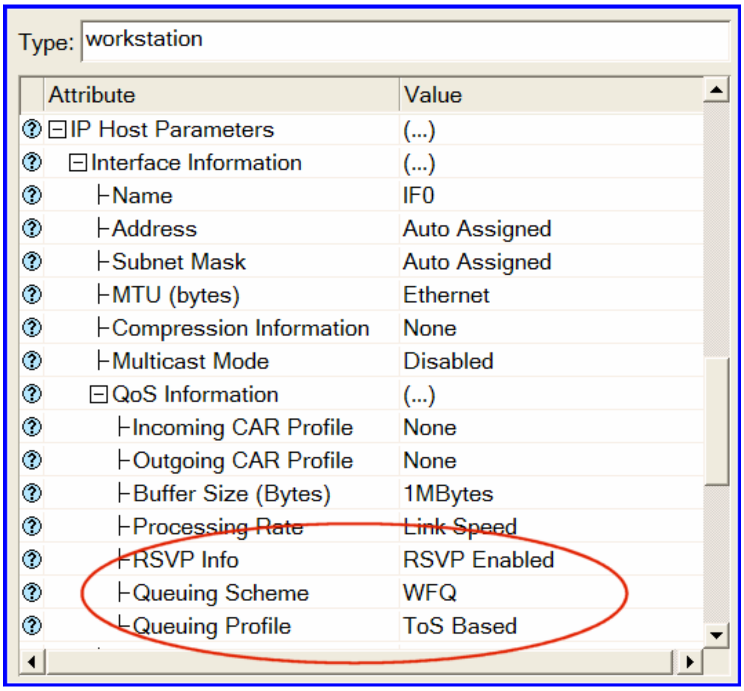
1. Right-click on the **Voice_RSVP Caller** node ⇒ **Edit Attributes**.

   i. Expand the **Application: Supported Profiles** hierarchy and its **row 0** hierarchy ⇒ Assign **VoIP_RSVP Profile** to the **Profile Name** attribute.

   ii. Expand the **Application: RSVP Parameters** hierarchy ⇒ Expand its **Voice** hierarchy ⇒ Enable the **RSVP Status** ⇒ Expand the **Profile List** hierarchy ⇒ Assign to the **Profile attribute** of **row 0** the value **RSVP_Profile**.



   iii. Expand the **IP Host Parameters** hierarchy ⇒ Expand its **Interface Information** hierarchy ⇒ Expand the **QoS Information** hierarchy ⇒ Assign **WFQ** to the **Queuing Scheme** attribute ⇒ Assign **ToS Based** to the **Queuing Profile attribute** ⇒ Assign **RSVP Enabled** to the **RSVP Info** attribute.

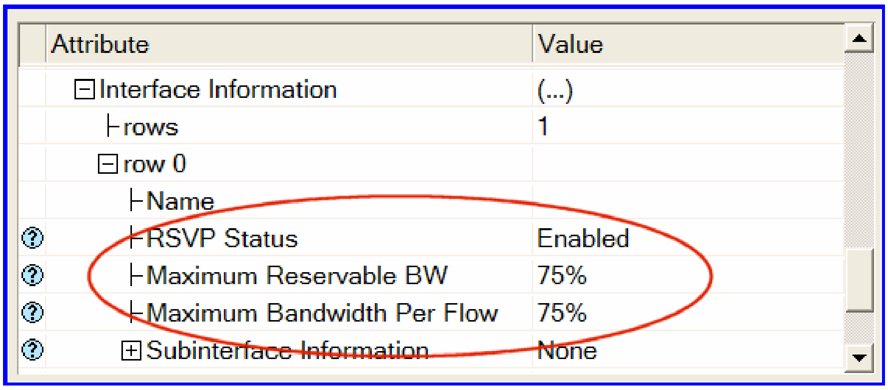


Type: workstation

Attribute	Value
IP Host Parameters	(...)
Interface Information	(...)
Name	IF0
Address	Auto Assigned
Subnet Mask	Auto Assigned
MTU (bytes)	Ethernet
Compression Information	None
Multicast Mode	Disabled
QoS Information	(...)
Incoming CAR Profile	None
Outgoing CAR Profile	None
Buffer Size (Bytes)	1MBytes
Processing Rate	Link Speed
RSVP Info	RSVP Enabled
Queuing Scheme	WFQ
Queuing Profile	ToS Based

Type of service (ToS) is assigned to the IP packets. It represents a session attribute that allows packets to be provided the appropriate service in the IP queues.

iv. Expand the **RSVP Protocol Parameters** hierarchy ⇒ Expand the **Interface Information** hierarchy. (You should notice that the word *Enabled* is listed in the summary line. When you expand it, you will see that it is the value of **RSVP Status**. If *Enabled* is not listed, go back to the *Configure the Interfaces* steps.) ⇒ Expand the hierarchy of the row of that interface ⇒ Assign **75%** to both the **Maximum Reservable BW** and **Maximum Bandwidth Per Flow** attributes as shown:



Attribute	Value
Interface Information	(...)
rows	1
row 0	
Name	
RSVP Status	Enabled
Maximum Reservable BW	75%
Maximum Bandwidth Per Flow	75%
Subinterface Information	None

v. Click **OK**.

Maximum Reservable BW specifies the percentage of the bandwidth of the connected link that RSVP can reserve on the interface.

Maximum Bandwidth Per Flow specifies the amount of reservable bandwidth that can be allocated to a single flow.

2. Right-click on the **Voice_RSVP Called** node ⇒ **Edit Attributes**.

   i. Edit the **Application: Supported Services** attribute. The *Application: Supported Services Table* will popup ⇒ In that table, replace the **VoIP Application** with **VoIP_RSVP** and Click **OK**.

   ii. Expand the **Application: RSVP Parameters** hierarchy ⇒ Expand its **Voice** hierarchy. ⇒ Enable the **RSVP Status** ⇒ Expand the **Profile List** hierarchy ⇒ Edit the value of the **Profile attribute** of **row 0** and enter **RSVP_Profile**.

iii. Expand the **IP Host Parameters** hierarchy ⇒ Expand its **Interface Information** hierarchy ⇒ Expand the **QoS Information** hierarchy ⇒ Assign **WFQ** to the **Queuing Scheme** attribute ⇒ Assign **ToS Based** to the **Queuing Profile attribute** ⇒ Assign **RSVP Enabled** to the **RSVP Info** attribute.

iv. Expand the **RSVP Protocol Parameters** hierarchy ⇒ Expand the **Interface Information** hierarchy. (You should notice that the **RSVP Status** of the interface that is connected to the router is *Enabled*. If not, go back to the *Configure the Interfaces* steps.) ⇒ Expand the hierarchy of the row of that interface ⇒ Assign **75%** to both **Maximum Reservable BW** and **Maximum Bandwidth Per Flow** attributes.

v. Click **OK**.

3. Right-click on the **East Router** node ⇒ **Edit Attributes**.

   i. Click on the **Ethernet4_slip8_gtwy** value of the **model** attribute. ⇒ Select **Edit** ⇒ Select the **Ethernet4_slip8_gtwy_adv** model.

   ii. Expand the **RSVP Protocol Parameters** hierarchy ⇒ Expand the **Interface Information** hierarchy. (You should notice that the **RSVP Status** of two interfaces, which are connected to the **West Router** and the **Voice_RSVP Called** node, are *Enabled*. If not, go back to the *Configure the Interfaces* steps.) ⇒ Expand the hierarchies of the rows of these two interfaces ⇒ Assign **75%** to both **Maximum Reservable BW** and **Maximum Bandwidth Per Flow** attributes.

   iii. Expand the **IP Routing Parameters** hierarchy ⇒ Expand the **Interface Information** hierarchy ⇒ Expand the hierarchies of the rows of the same two interfaces you configured in the previous step (step ii) ⇒ Expand the **QoS Information** hierarchy for both ⇒ Set **Queuing Scheme** to **WFQ** and **Queuing Profile** to **ToS Based** for both.

   iv. Click **OK**.

4. Right-click on the **West Router** node ⇒ **Edit Attributes**.

   i. Click on the **Ethernet4_slip8_gtwy** value of the **model** attribute ⇒ Select **Edit** ⇒ Select the **Ethernet4_slip8_gtwy_adv** model.

   ii. Expand the **RSVP Protocol Parameters** hierarchy ⇒ Expand the **Interface Information** hierarchy. (You should notice that the **RSVP Status** of two interfaces, which are connected to the **East Router** and the **Voice_RSVP Caller** node, are *Enabled.* If not, go back to the *Configure the Interfaces* steps.) ⇒ Expand the hierarchies of the rows of these two interfaces ⇒ Assign **75%** to both **Maximum Reservable BW** and **Maximum Bandwidth Per Flow** attributes.

   iii. Expand the **IP Routing Parameters** hierarchy ⇒ Expand the **Interface Information** hierarchy ⇒ Expand the hierarchies of the rows of the same two interfaces you configured in the previous step (step ii) ⇒ Expand the **QoS Information** hierarchy for both ⇒ Set **Queuing Scheme** to **WFQ** and **Queuing Profile** to **ToS Based** for both.

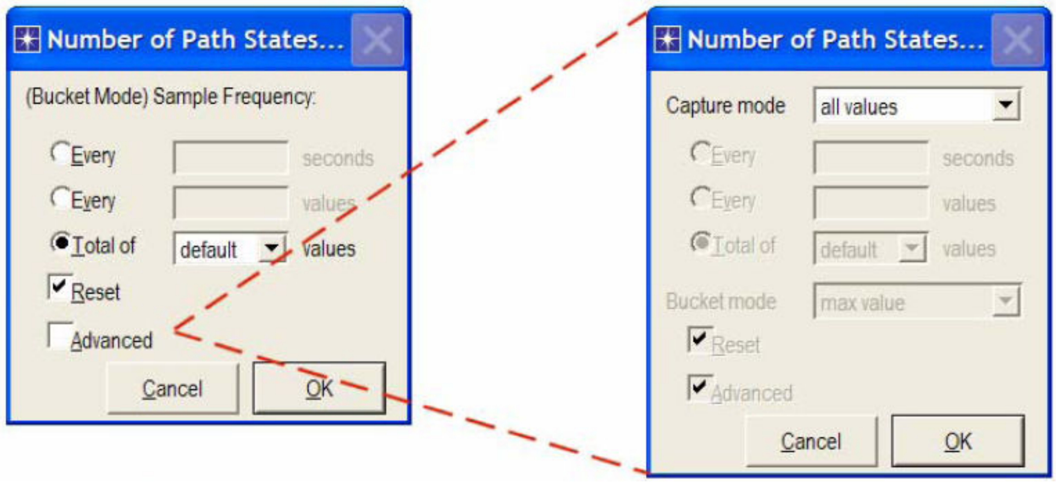
   iv. Click **OK**.

11.4.3. Choose the Statistics

We will select statistics from three different nodes:

11.4.3.1. Voice_RSVP Caller Statistics:

1. Right-click on the **Voice_RSVP Caller** node and select **Choose Individual Statistics** from the pop-up menu.
2. Expand the **RSVP** hierarchy and select **Number of Path States**.
3. Right-click on the **Number of Path States** statistic ⇒ Select **Change Draw Style** from the pop-up menu ⇒ Choose **bar chart**.
4. Right-click on the **Number of Path States** statistic ⇒ Select **Change Collection Mode** from the pop-up menu ⇒ Check the **Advanced** checkbox ⇒ From the **Capture mode** drop-down menu, select **all values**, as shown ⇒ Click **OK**.



5. Expand the **Voice Calling Party** hierarchy and select the following statistics: **Packet Delay Variation** and **Packet End-to-End Delay (sec)**.
6. Click **OK**.

Packet Delay Variation is the variance among end-to-end delays for voice packets received by this node.

Packet End-to-End Delay for a voice packet is measured from the time it is created to the time it is received.

11.4.3.2. Voice_RSVP Called Statistics:

1. Right-click on the **Voice_RSVP Called** node and select **Choose Individual Statistics** from the pop-up menu.
2. Expand the **RSVP** hierarchy and select **Number of Resv States**.
3. Right-click on the **Number of Resv States** statistic ⇒ Select **Change Draw Style** from the pop-up menu ⇒ Choose **bar chart**.
4. Right-click on the **Number of Resv States** statistic ⇒ Select **Change Collection Mode** from the pop-up menu ⇒ Check the **Advanced** checkbox ⇒ From the **Capture mode** drop-down menu, select **all values** ⇒ Click **OK**.
5. Click **OK**.

11.4.3.3. Voice Caller Statistics:

1. Right-click on the **Voice Caller** node and select **Choose Individual Statistics** from the pop-up menu.
2. Expand the **Voice Calling Party** hierarchy and select the following statistics: **Packet Delay Variation** and **Packet End-to-End Delay (sec)**.
3. Click **OK**.

11.4.4. Configure the Simulation

Here, we need to configure the duration of the simulation:

1. Click on  and the *Configure Simulation* window should appear.
2. Make sure that the duration is set to **150 seconds**.
3. Click on the **Global Attributes** tab and make sure that the following attribute is enabled:
    a. **RSVP Sim Efficiency = Enabled.** This decreases the simulation time and memory requirements by not sending refresh messages (i.e., Path and Resv refreshes).
4. Click **OK** and then save your project.

11.4.5. Run the Simulation

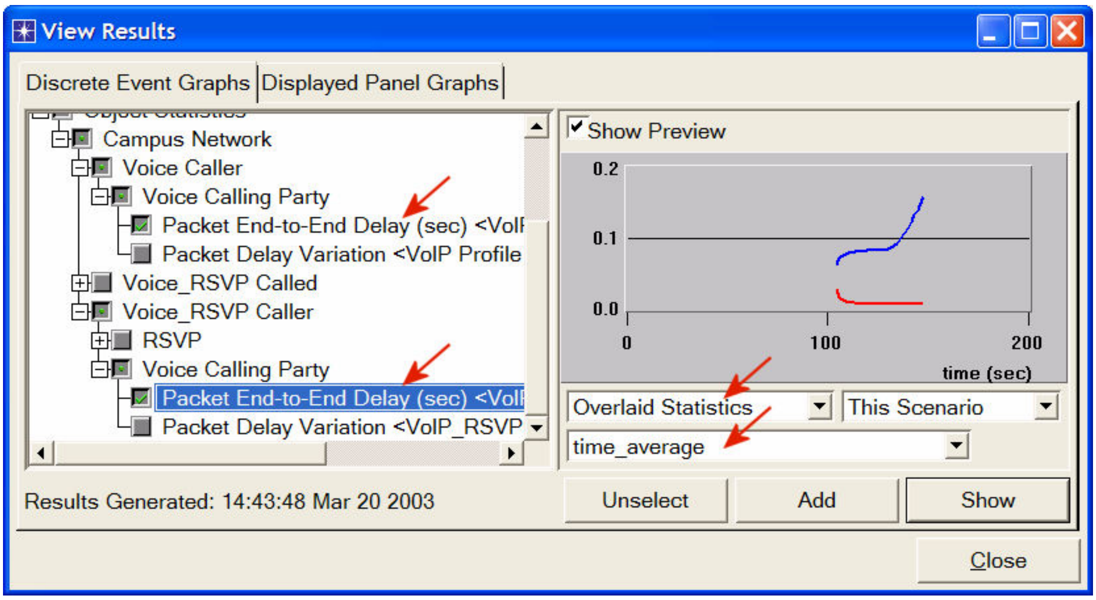
To run the simulation:

1. Click on  and then click the **Run** button. Depending on the speed of your processor, this may take several minutes to complete.
2. After the simulation completes, click **Close.**
3. Save your project.

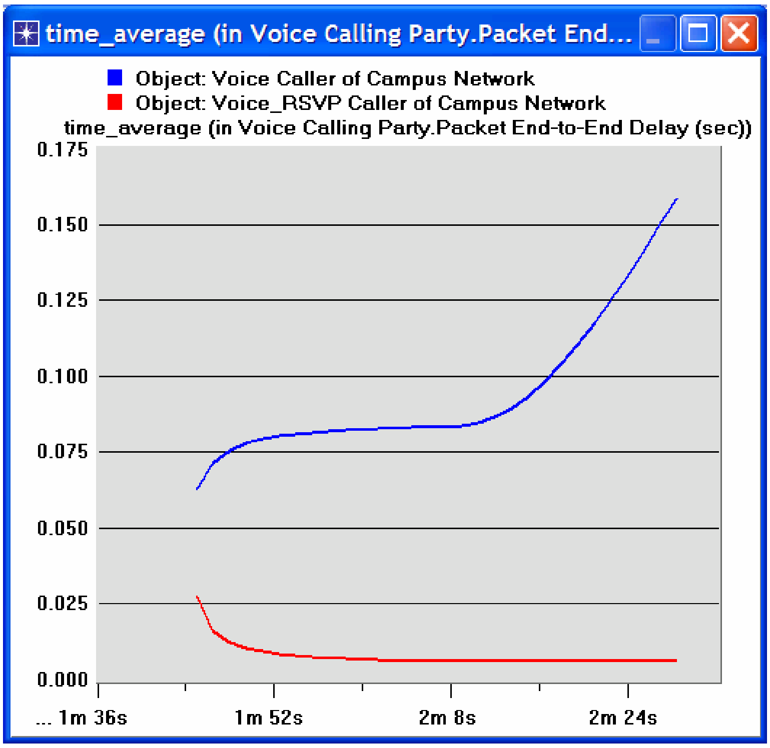
11.4.6. View the Results

To view and analyze the results:

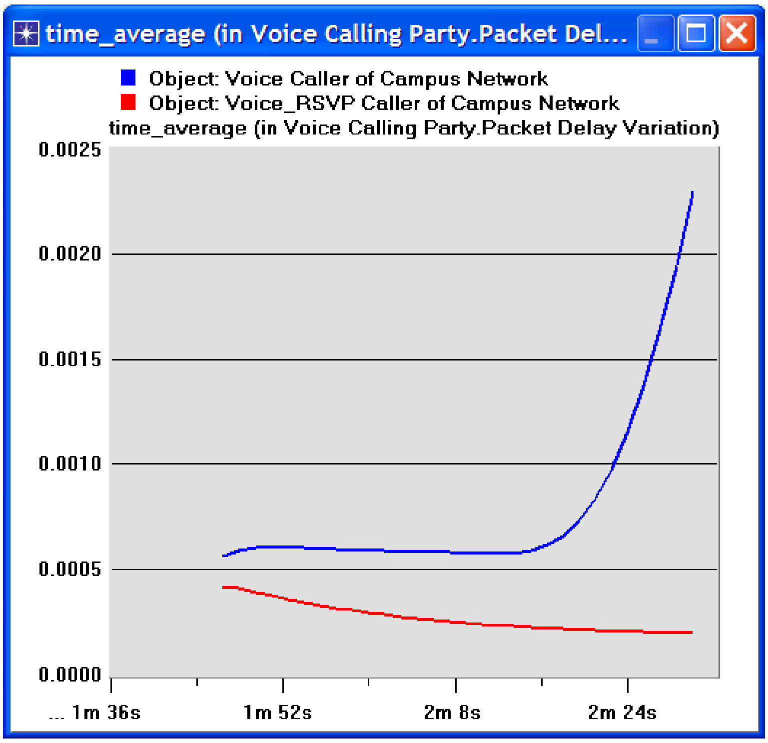
1. Select **View Results** from the **Results** menu.
2. As shown in the following figure, choose the **Packet End_to_End Delay** for both the **Voice Caller** and **Voice_RSVP Caller** nodes. Choose **Overlaid Statistics** and **time_average**.



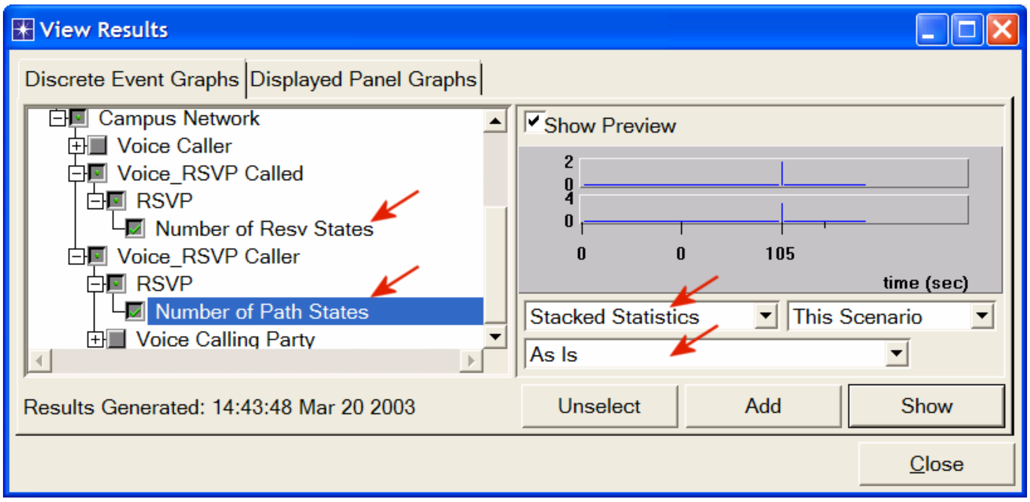
3. Click **Show** to get the following graph. (*Note*: To zoom in on the graph, click and drag your mouse to draw a rectangle around the area of interest and release the mouse button.)



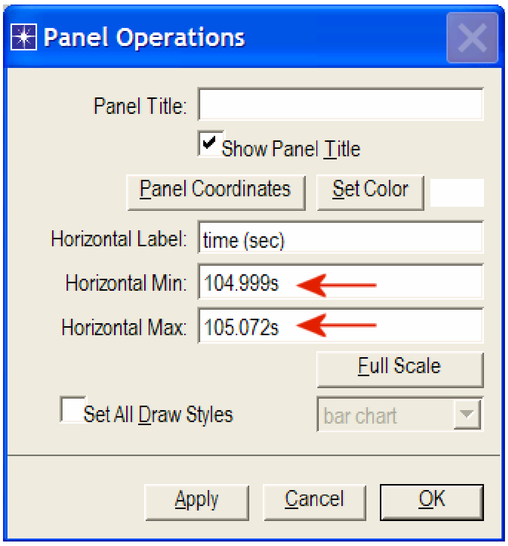
4. Similarly, you can get the following graph that compares the **Packet Delay Variation** for both the **Voice Caller** and **Voice_RSVP Caller** nodes. (*Note*: Make sure to "unselect" the statistics you chose for the previous graph.)



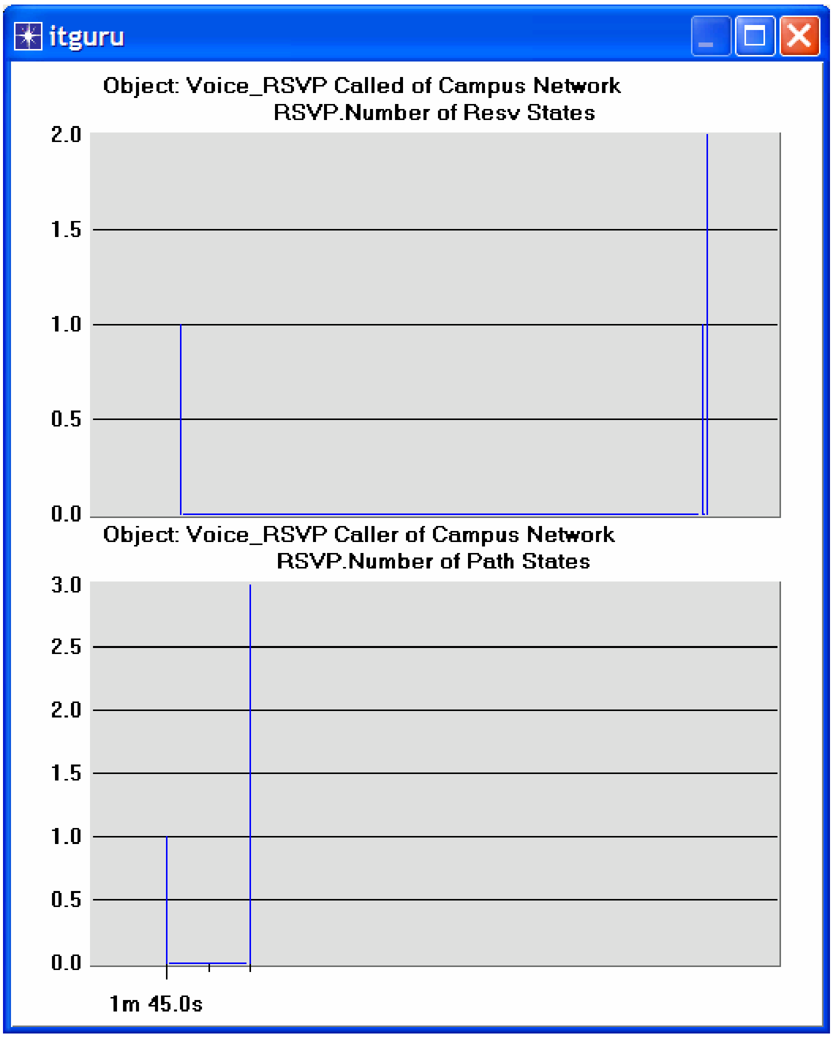
5. Finally, prepare the graph that displays the number of Path and Resv states by selecting the following statistics. Make sure to select **Stacked Statistics** and **As Is** as shown.



6. Right-click on the resulting graph and choose **Edit Panel Properties** ⇒ Change the assigned values to the **Horizontal Min** and **Horizontal Max** fields as shown (your graph might require a slightly different range):



7. Click **OK**. The resulting graph should resemble the one below.



11.5. *Further readings*

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

11.6. *Exercises*

1) Analyze the graphs we obtained in this lab. Show the effect of RSVP on the Voice application and explain the obtained numbers of Path and Resv states.

2) How does the data rate of the link connecting the **East** and **West** routers affect the performance (e.g., **Packet End-to-End Delay)** of the Voice and Video Conference applications? To answer this question, create a new scenario as a duplicate of the **QoS_RSVP** scenario. Name the new scenario **Q2_HighRate**. In the **Q2_HighRate** scenario replace the current **PPP_DS1** link (data rate 1.544 Mbps) with a **PPP_DS3** link (data rate 44.736 Mbps).

11.7. *Lab Report*

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

12. Laboratory - Firewalls and VPN (Network Security and Virtual Private Networks)

12.1. *Objective*

The objective of this lab is to study the role of firewalls and Virtual Private Networks VPNs) in providing security to shared public networks such as the Internet.

12.2. *Overview*

Computer networks are typically a shared resource used by many applications for many different purposes. Sometimes the data transmitted between application processes is confidential, and the application users would prefer that others not be able to read it.

A firewall is a specially programmed router that sits between a site and the rest of the network. It is a router in the sense that it is connected to two or more physical networks and it forwards packets from one network to another, but it also fitters the packets that flow through it. A firewall allows the system administrator to implement a security policy in one centralized place. File-based firewalls are the simplest and most widely deployed type of firewall. They are configured with a table of addresses that characterize the packets they will and will not forward.

A VPN is an example of providing a controlled connectivity over a public network such as the Internet. VPNs utilize a concept called an *IP tunnel* - a virtual point-to-point link between a pair of nodes that are actually separated by an arbitrary number of networks. The virtual link is created within the router at the entrance to the tunnel by providing it with the IP address of the router at the far end of the tunnel. Whenever the router at the entrance of the tunnel wants to send a packet over this virtual link, it encapsulates the packet inside an IP datagram. The destination address in the IP header is the address of the router at the far end of the tunnel, white the source address is that of the encapsulating router.

In this lab you will set up a network where servers are accessed over the Internet by customers who have different privileges. You will study how firewalls and VPNs can provide security to the information in the servers while maintaining access for customers with the appropriate privilege.

12.3. *Prelab Activities*

- Read section 4.5.3 from *"Computer Networks: A Systems Approach"*, 4th *Edition.*
    - Firewalls

12.4. *Procedure*

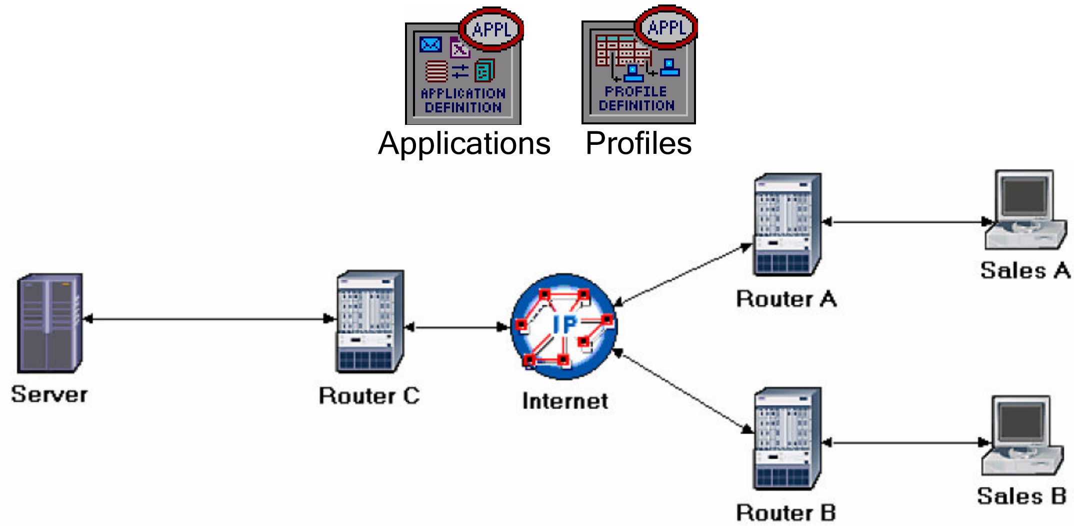
12.4.1. Create a New Project

1. Start **OPNET IT Guru Academic Edition** ⇒ Choose **New** from the **File** menu.
2. Select **Project** and Click **OK** ⇒ Name the project **<your initials>_VPN**, and the scenario **NoFirewall** ⇒ Click **OK**.
3. Click **Quit** on the *Startup Wizard*.
4. To remove the world background map, select the **View** menu ⇒ **Background** ⇒ **Set Border Map** ⇒ Select **NONE** from the drop-down menu ⇒ Click **OK**.

12.4.2. Create and Configure the Network

12.4.2.1. Initialize the Network:

1. Open the **Object Palette** dialog box by clicking . Make sure that the **internet_toolbox** item is selected from the pull-down menu on the object palette.
2. Add the following objects, from the palette, to the project workspace (see figure below for placement): **Application Config**, **Profile Config**, an **ip32_cloud**, one **ppp_server**, three **ethernet4_slip8_gtwy** routers, and two **ppp_wkstn** hosts.
   a. To add an object from a palette, click its icon in the object palette. ⇒ Move your mouse to the workspace and click where you want to place the object. ⇒ Right-click to indicate you are done creating objects of this type.
3. Rename the objects you added and connect them using **PPP_DS1** links, as shown below:



4. Save your project.

The **ppp_server** and **ppp_wkstn** support one underlying SLIP (Serial Line Internet Protocol) connection at a selectable data rate. **PPP_DS1** connects two nodes running PPP. Its data rate is 1.344 Mbps.

12.4.2.2. Configure the Nodes:

1. Right-click on the **Applications** node ⇒ **Edit Attributes** ⇒ Assign **Default** to the **Application Definitions** attribute ⇒ Click **OK**.
2. Right-click on the **Profiles** node ⇒ **Edit Attributes** ⇒ Assign **Sample Profiles** to the **Profile Configuration** attribute ⇒ Click **OK**.
3. Right-click on the **Server** node ⇒ **Edit Attributes** ⇒ Assign **All** to the **Application: Supported Services** attribute ⇒ Click **OK**.
4. Right-click on the **Sales A** node ⇒ **Select Similar Nodes** (make sure that both **Sales A** and **Sales B** are selected).
   i. Right-click on the **Sales A** node ⇒ **Edit Attributes** ⇒ Check the **Apply Changes to Selected Objects** check-box.
   ii. Expand the **Application: Supported Profiles** attribute ⇒ Set **rows** to **1** ⇒ Expand the **row 0** hierarchy ⇒ **Profile Name = Sales Person** (this is one of the "sample profiles" we configured in the **Profiles** node).

iii. Click **OK**.

5. Save your project.

Several examples application configurations are available under the Default setting. For example, "Web Browsing (Heavy HTTP1.1)" indicates a Web browsing application performing heavy browsing using HTTP1.1. protocol.

12.4.3. Choose the Statistics

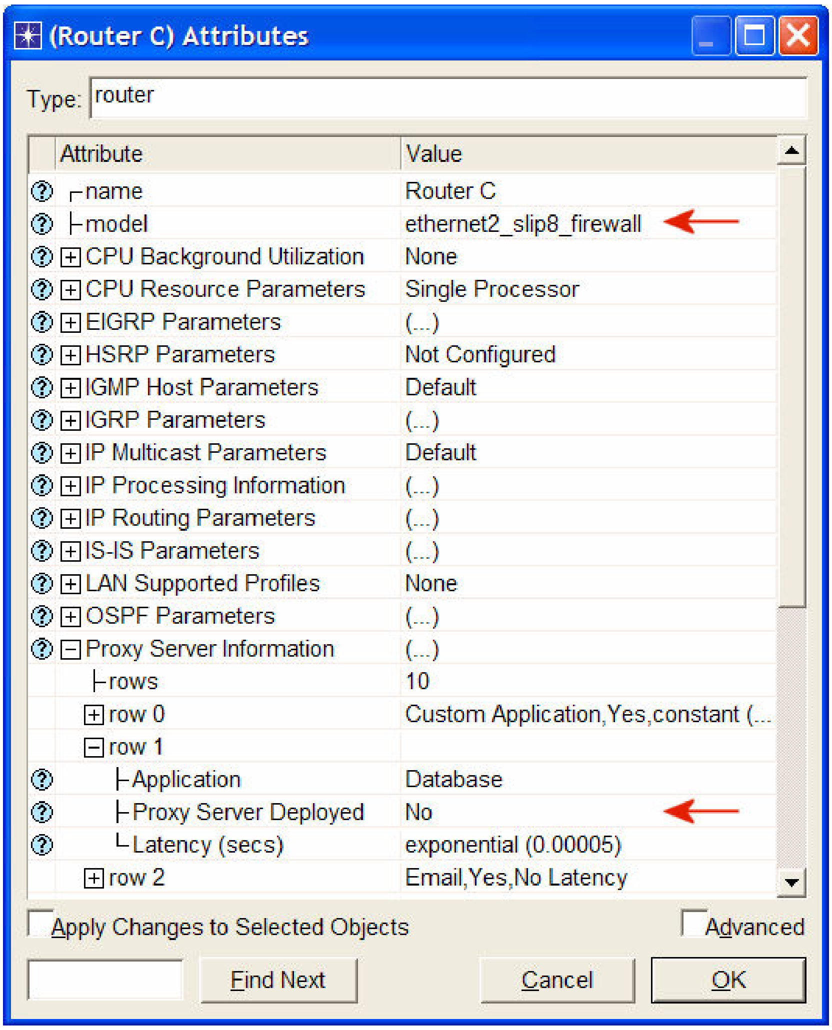
1. Right-click anywhere in the project workspace and select **Choose Individual Statistics** from the pop-up menu.
2. In the *Choose Results* dialog, check the following statistics:
   i. **Global Statistics** ⇒ **DB Query** ⇒ **Response Time (sec)**.
   ii. **Global Statistics** ⇒ **HTTP** ⇒ **Page Response Time (seconds)**.
3. Click **OK**.
4. Right-click on the **Sales A** node and select **Choose Individual Statistics** from the pop-up menu.
5. In the *Choose Results* dialog, check the following statistics:
   i. **Client DB** ⇒ **Traffic Received (bytes/sec)**.
   ii. **Client Http** ⇒ **Traffic Received (bytes/sec)**.
6. Click **OK**.
7. Right-click on the **Sales B** node and select **Choose Individual Statistics** from the pop-up menu.
8. In the *Choose Results* dialog, check the following statistics:
   i. **Client DB** ⇒ **Traffic Received (bytes/sec)**.
   ii. **Client Http** ⇒ **Traffic Received (bytes/sec)**.
9. Click **OK** and then save your project.

DQ Query Response Time is measured from the time when the database query application sends a request to the server to the time it receives a response packet. **HTTP Page Response Time** specifies the time required to retrieve the entire page with all the contained inline objects.

12.4.4. The Firewall Scenario

In the network we just created, the **Sales Person** profile allows both sales sites to access applications such as Database Access, Email, and Web Browsing from the server (check the **Profile Configuration** of the **Profiles** node) Assume that we need to protect the database in the server from external access, including the sales people. One way to do that is to replace **Router C** with a firewall as follows:

1. Select **Duplicate Scenario** from the **Scenarios** menu and name it **Firewall** ⇒ Click **OK.**
2. In the new scenario, right-click on **Router C** ⇒ **Edit Attributes.**
3. Assign **ethernet2_slip8_firewall** to the **model** attribute.
4. Expand the hierarchy of the **Proxy Server Information** attribute ⇒ Expand the **row 1**, which is for the Database application, hierarchy ⇒ Assign **No** to the **Proxy Server Deployed** attribute as shown:

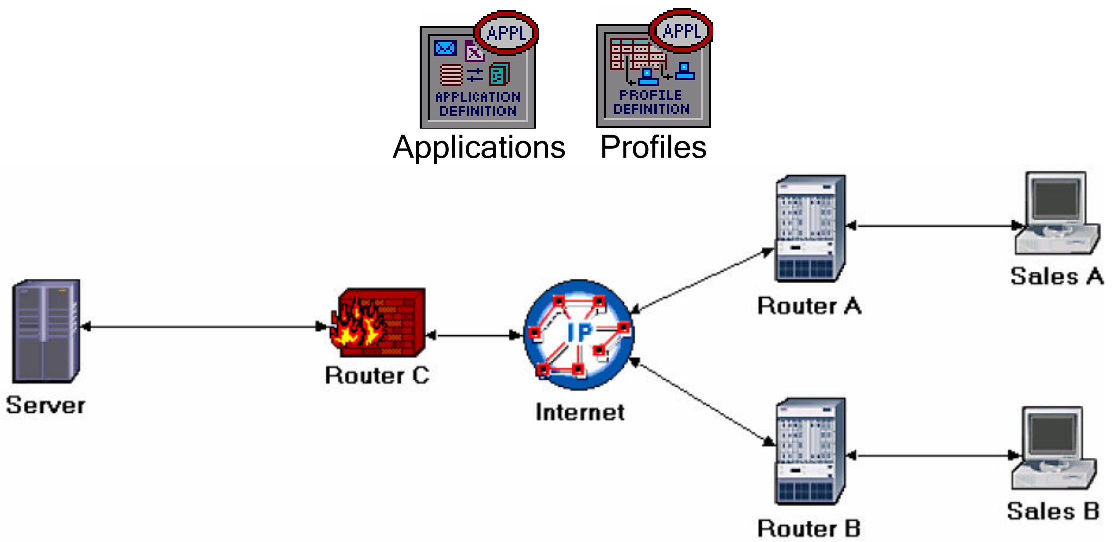


5. Click **OK** and then save your project.

Proxy Server Information is a table defining the configuration of the firewall. Each roe indicates whether a proxy server exists for a certain application and the amount of additional delay that will be introduced to each forwarded packet of that application by the proxy server.

12.4.5. Firewalls and VPN

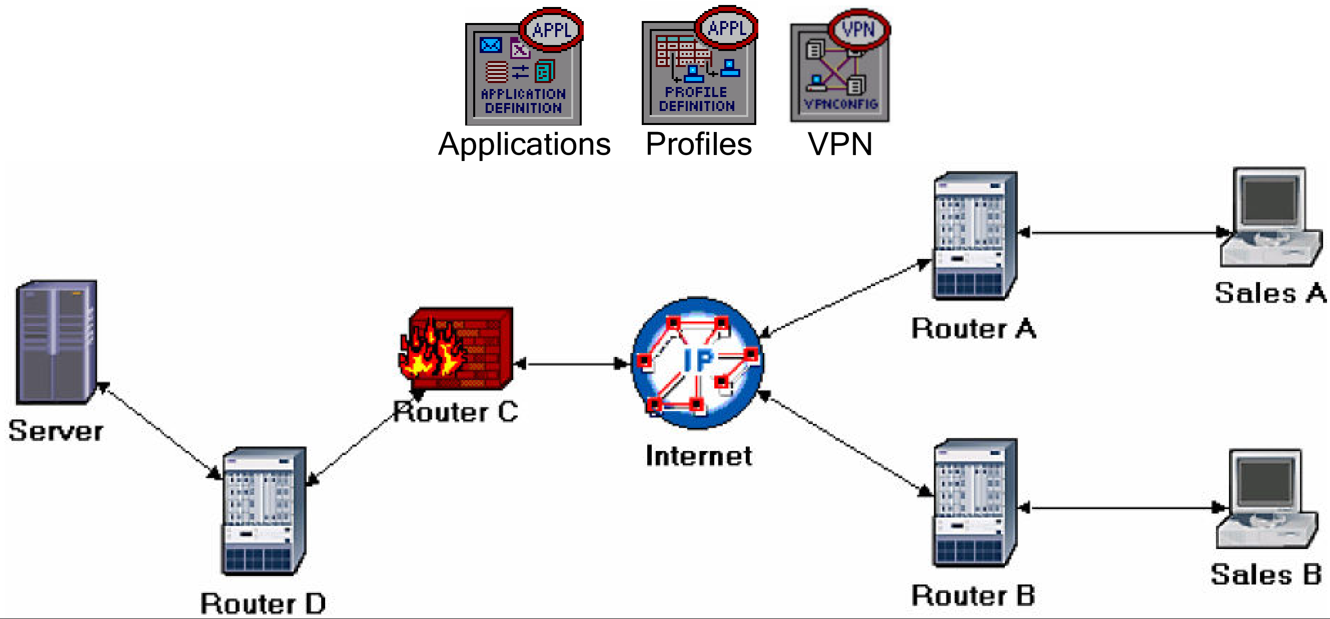
Our **Firewall** configuration does not allow database-related traffic to pass through the firewall (it filters such packets out). This way, the databases in the server are protected from external access. Your **Firewall** scenario should look like the following figure.



12.4.6. The Firewall VPN Scenario

In the **Firewall** scenario, we protected the databases in the server from "any" external access using a firewall router. Assume that we want to allow the people in the **Sales A** site to have access to the databases in the server. Since the firewall fitters all database-related traffic regardless of the source of the traffic, we need to consider the VPN solution. A virtual tunnel can be used by **Sales A** to send database requests to the server. The firewall will not filter the traffic created by **Sales A** because the IP packets in the tunnel will be encapsulated inside an IP datagram.

1. While you are in the **Firewall** scenario, select **Duplicate Scenario** from the **Scenarios** menu and give it the name **Firewall_VPN** ⇒ Click **OK**.
2. Remove the link between **Router C** and the **Server.**
3. Open the *Object Palette* dialog box by clicking . Make sure that the **internet_toolbox** is selected from the pull-down menu on the object palette.
   i. Add to the project workspace one **ethernet4_slip8_gtwy** and one **IP VPN Config** (see the figure below for placement).
   ii. From the *Object Palette*, use two **PPP_DS1** links to connect the new router to **Router C** (the firewall) and to the **Server**, as shown below.
   iii. Close the *Object Palette* dialog box.
4. Rename the **IP VPN Config** object to **VPN**.
5. Rename the new router to **Router D** as shown:



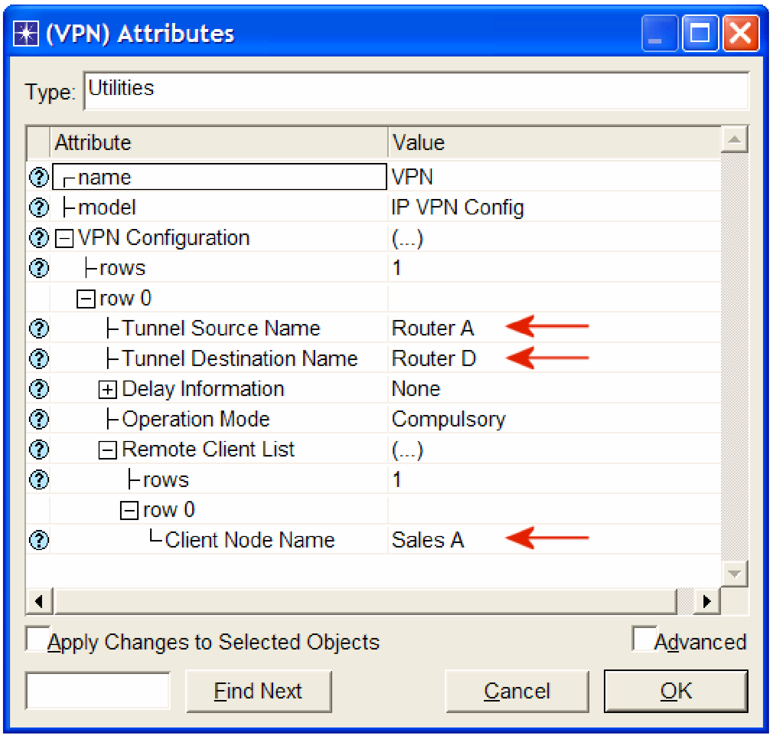
The **ethernet4_slip8_gtwy** node model represents an IP based gateway supporting four Ethernet hub interfaces and eight serial line interfaces: IP packets arriving on any interface are routed to the appropriate output interface based on their destination IP address. The Routing Interface Protocol (RIP) or the Open Shortest Path First (OSPF) protocol may be used to dynamically and automatically create the gateway's routing tables and select routers in an adaptive manner.

12.4.6.1. Configure the VPN:

1. Right-click on the **VPN** node ⇒ **Edit Attributes**.
   i. Expand the **VPN Configuration** hierarchy ⇒ Set **rows** to **1** ⇒ Expand **row 0** hierarchy ⇒ Edit the value of **Tunnel Source Name** and enter **Router A** ⇒ Edit the value of **Tunnel Destination Name** and enter **Router D**.

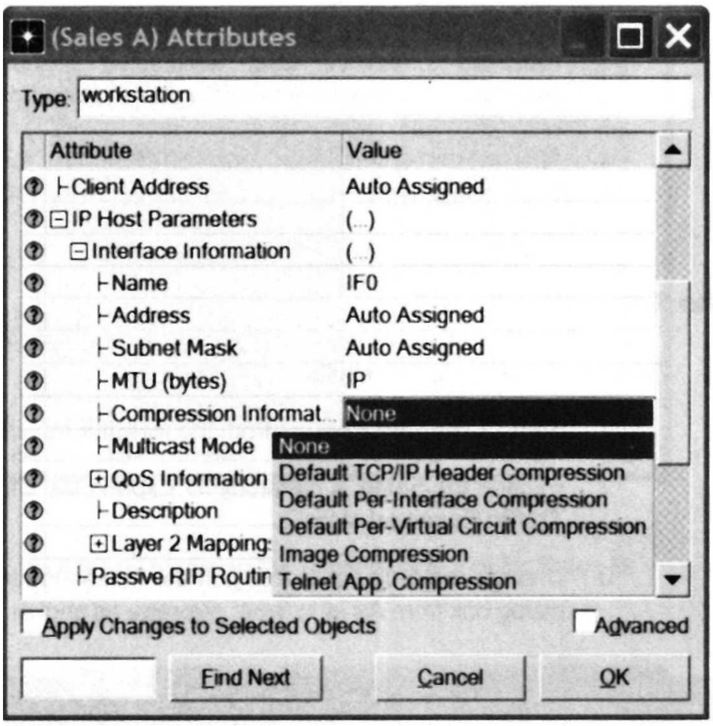
ii. Expand the **Remote Client List** hierarchy ⇒ Set **rows** to **1** ⇒ Expand **row 0** hierarchy ⇒ Edit the value of **Client Node Name** and enter **Sales A**.

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



12.4.6.2. Simulating Encryption:

A virtual tunnel between **Sales A** and the **Server** does not guarantee security for the contents of the transferred database packets. If the contents of these packets are confidential, encryption of these packets will be needed. In OPNET AE, the effect of packets encryption can be simulated by the available compression function. Two of the available compression schemes are the Per-Interface Compression and the Per-Virtual Circuit Compression as shown. Once you edit the Compression Information attribute of an interface, OPNET adds the IP Config node to the project.



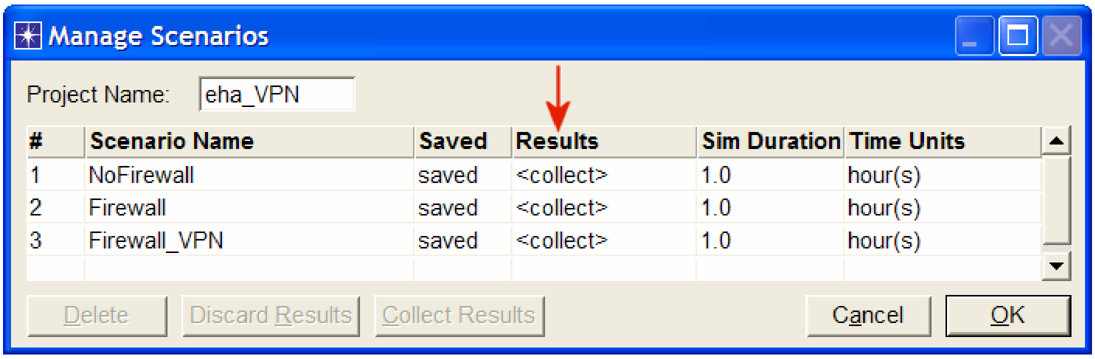
Change picture!

Per-Interface Compression compresses the entire packet (including the headers). This means the packet is decompressed and compressed at each hop on the route Per-Virtual Circuit Compression compresses the packet payload only. Therefore, compression and decompression take place only at the end nodes. One of the exercises by the end of this lab will ask you to create a new scenario to utilize the compression function.

12.4.7. 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. Keep the default value of the **Sim Duration** (1 hour). Compare to the following figure.

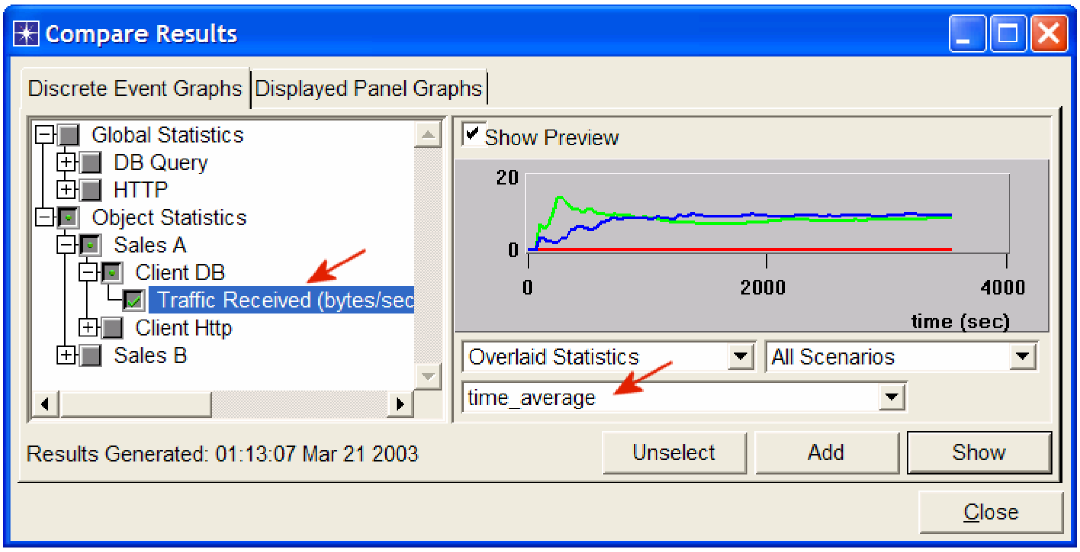


3. Click **OK** to run the three simulations. Depending on the speed of your processor, this may take several minutes to complete.
4. After the three simulation runs complete, one for each scenario, click **Close** ⇒ Save your project.

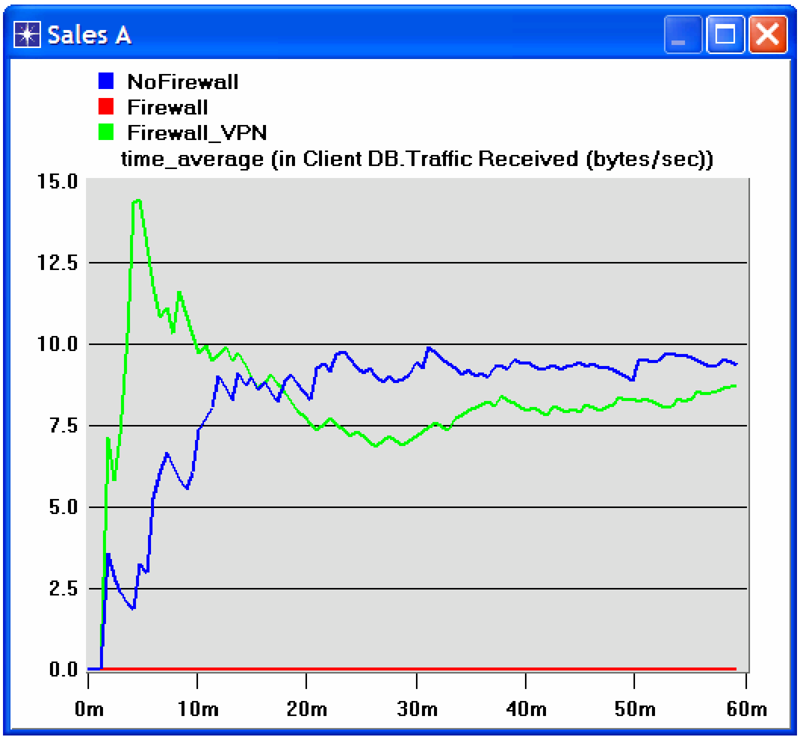
12.4.8. View the Results

To view and analyze the results:

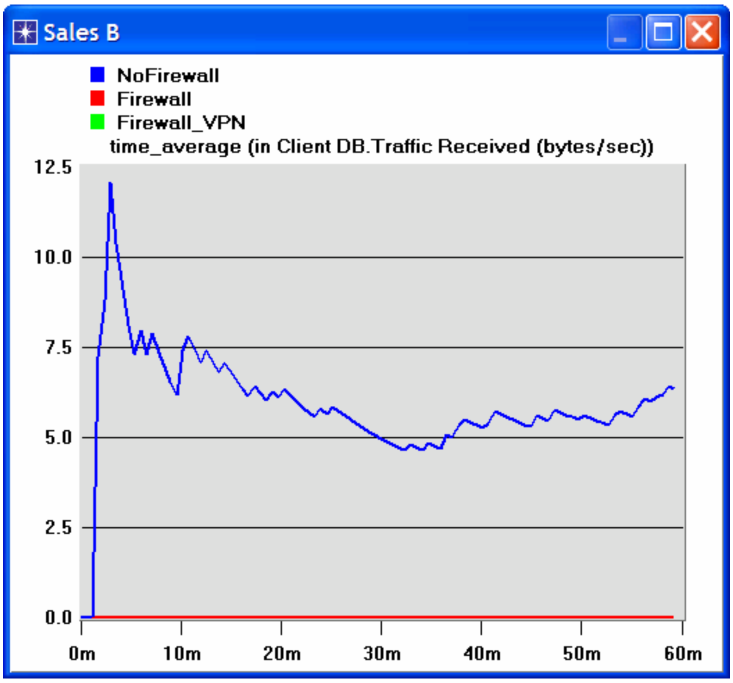
1. Select **Compare Results** from the **Results** menu.
2. Expand the **Sales A** hierarchy ⇒ Expand the **Client DB** hierarchy ⇒ Select the **Traffic Received** statistic.
3. Change the drop-down menu in the middle-lower part of the **Compare Results** dialog box from **As_Is** to **time_average** as shown.



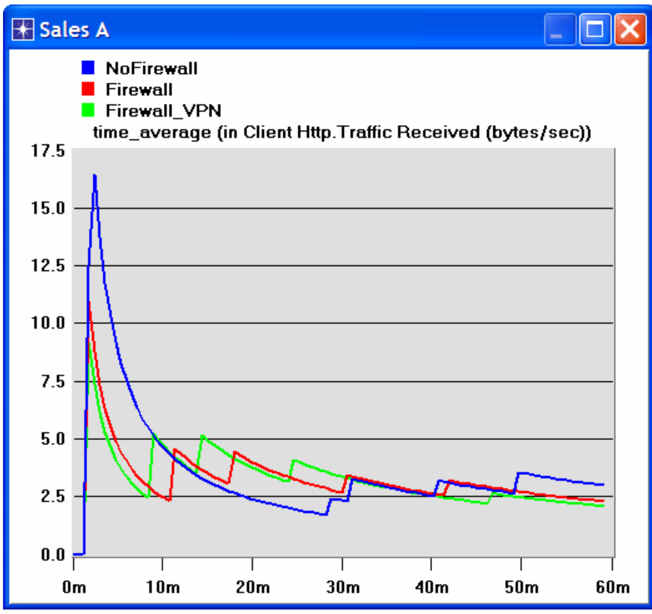
4. Press **Show** and the resulting graph should look similar to the following figure. Your graph may not match exactly due to node placement.

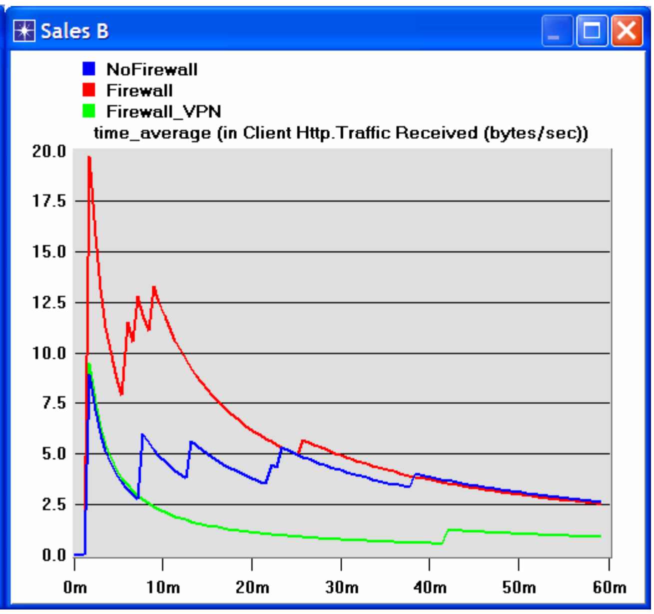


5. Create a graph similar to the previous one, but for **Sales B**:



6. Create two graphs similar to the previous ones to depict the **Traffic Received** by the **Client Http** for **Sales A** and **Sales B**.





Note: Results may vary slightly due to different node placement.

12.5. *Further readings*

- The Impact of Internet Link Capacity on Application Performance: From the **Protocols** menu, select **Methodologies** ⇒ Capacity Planning.
- Virtual Private Networks Management: IETF RFC number 2685 (www.ietf.org/rfc.html).

12.6. *Exercises*

1) From the obtained graphs, explain the effect of the firewall, as well as the configured VPN, on the database traffic requested by **Sales A** and **Sales B.**
2) Compare the graphs that show the received HTTP traffic with those that show the received database traffic.

3) Generate and analyze the graph(s) that show the effect of the firewall, as well as the configured VPN, on the response time (delay) of the HTTP pages and database queries.

4) In the **Firewall_VPN** scenario we configured the **VPN** node so that no traffic from **Sales A** is blocked by the firewall. Create a duplicate of the **Firewall_VPN** scenario and name the new scenario **Q4_DB_Web**. In the **Q4_DB_Web** scenario we want to configure the network so that:

   a. The databases in the server can be accessed only by the people in the **Sales A** site.

   b. The web sites in the server can be accessed only by the people in the **Sales B** site.

   Include in your report the diagram of the new network configuration including any changes you made to the attributes of the existing or added nodes. Generate the graphs of the DB traffic received and the HTTP traffic received for both **Sales A** and **Sales B** to show that the new network meets the above requirements.

5) Create a duplicate of the **Firewall_VPN** scenario and name the new scenario **Q5_Compression**. In the new scenario simulate packet encryption between **Sales A** and the **Server** by allowing **Per-Virtual Circuit Compression** in both nodes. As encryption takes more time than compression, edit the attributes of the Per-Virtual Circuit Compression row (row 3) in the **IP Config** node. Assign 3E-006 and 1E-006 to **Compression Delay** and **Decompression Delay** respectively. Study the effect of compression on the DB Query response time between **Sales A** and the **Server.**

12.7. *Lab Report*

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

13. Laboratory - Applications (Network Application Performance Analysis)

13.1. *Objective*

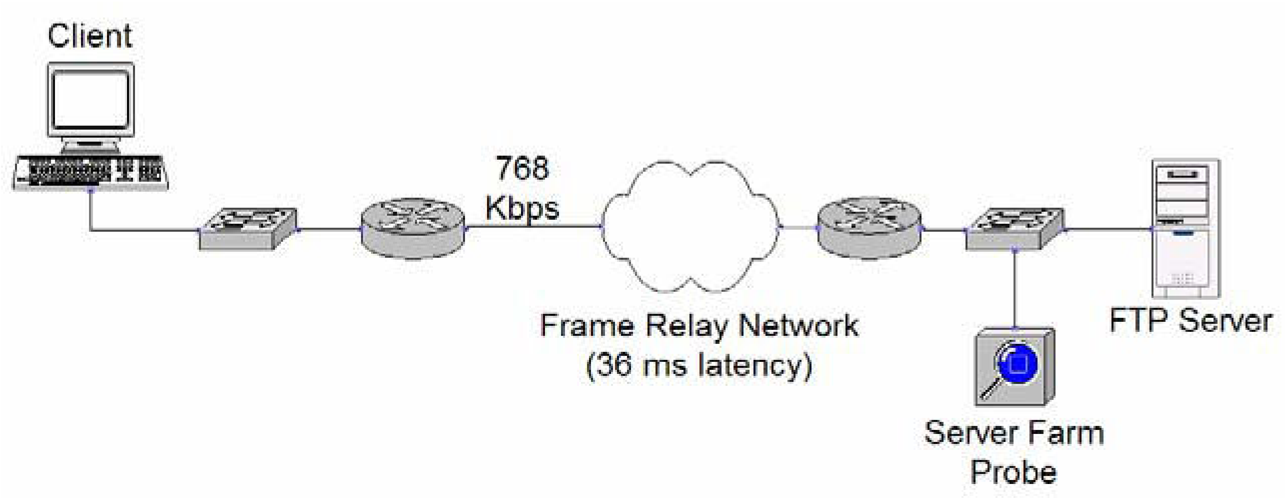
The objective of this lab is to analyze the performance of an Internet application protocol and its relation to the underlying network protocols. In addition, this lab reviews some of the topics covered in previous labs.

13.2. *Overview*

Network applications are part network protocol (in the sense that they exchange messages with their peers on other machines) and part traditional application program (in the sense that they interact with the users).

OPNET's Application Characterization Environment (ACE) provides powerful visualization and diagnosis capabilities that aid in network application analysis. ACE provides specific information about the root cause of application problems. ACE can also be used to predict application behavior under different scenarios. ACE takes as input a real trace file captured using any protocol analyzer, or using OPNET's capture agents (not included in the Academic Edition).

In this lab you will analyze the performance of an FTP application. You will analyze the probable bottlenecks for the application scenario under investigation. You will also study the sensitivity of the application to different network conditions such as bandwidth and packet loss. The trace was captured on a real network, which is shown in the figure below, and already imported into ACE. The FTP application runs on that network; the client connects to the server over a 768 Kbps Frame Relay circuit with 36 ms of latency. The FTP application downloads a 1 MB file in 37 seconds. Normally the download time for a file this size should be about 11 seconds.



13.3. *Prelab Activities*

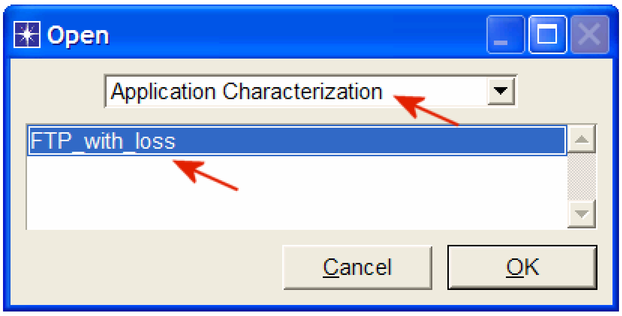
- Read sections 9.1.1 and 9.1.3 from ***"Computer Networks: A Systems Approach"*** 4th ***Edition***.

  Go to ***www.net-seal.net/animations.php*** and play the following animations:
  - Internet Access.
  - Email Protocols

13.4. *Procedure*

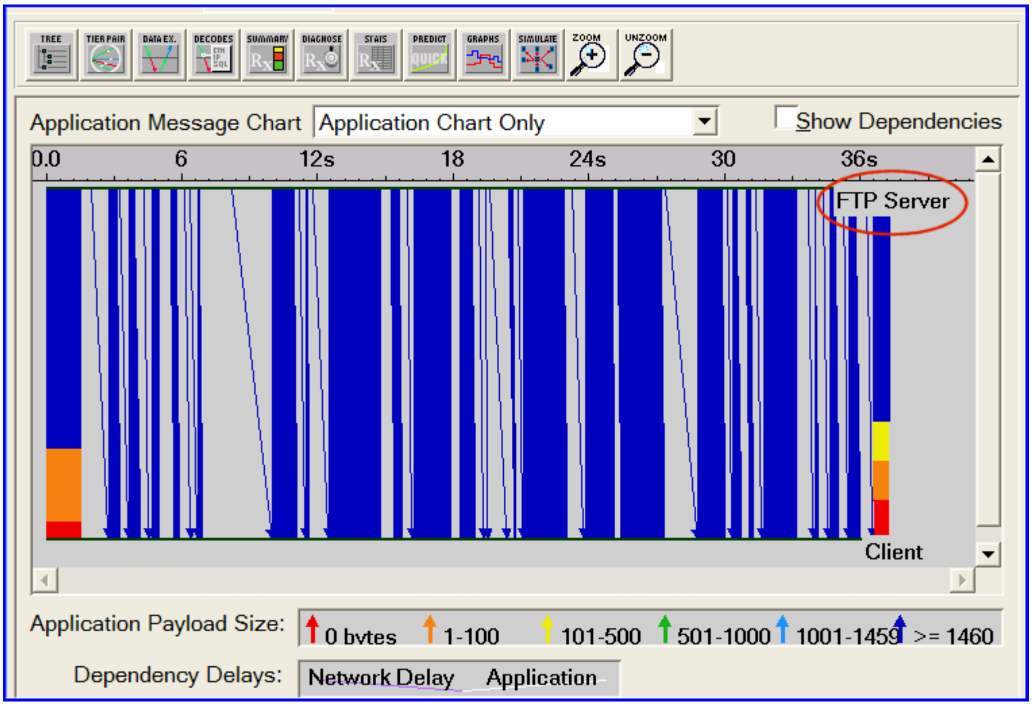
13.4.1. Open the Application Characterization Environment

1. Start **OPNET IT Guru Academic Edition** ⇒ Choose **Open** from the **File** menu.
2. Select **Application Characterization** from the pull-down menu.
3. Select **FTP_with_loss** from the list ⇒ Click **OK**.



13.4.2. Visualize the Application

After opening the file, ACE shows the Data Exchange Chart (DEC), depicting the flow of application traffic between tiers. The DEC you see on your screen may or may not show the **FTP Server** tier as the top tier. If it does not, drag the tier label from the bottom to the top, so your screen matches the one shown in the following diagram.

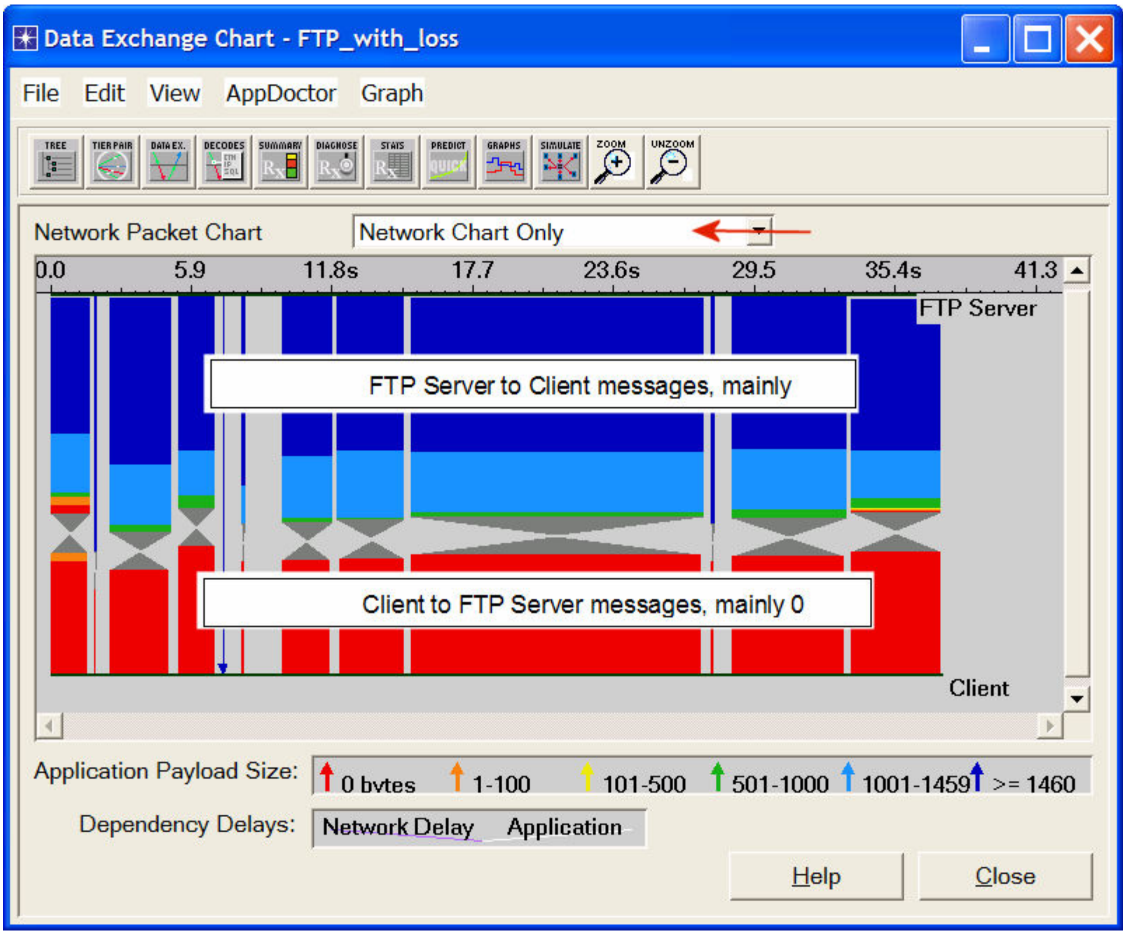


1. Select **Network Chart Only** from the drop-down menu as shown below.
2. Differentiate the messages flowing in different directions by selecting **View** ⇒ **Split Groups**.

The **Data Exchange Chart** can display the following:

- The **Application Chart**, which shows the flow of application traffic between nets.
- The **Network Chart**, which shows the flow of network protocols on application traffic.

Network protocols split packets into segments, add header, and often include mechanisms to ensure reliable data transfer. These network protocol effects can influence application behavior.



To get a better understanding of this traffic, you will zoom in on the transaction. To understand how the Application Chart and Network Chart views differ, you will view both simultaneously.

3. Select **Application and Network Charts** from the drop-down menu in the middle of the dialog box.

4. To disable the split groups view, select **View** ⇒ **Split Groups**.

5. Select **View** ⇒ Set **Visible Time Range** ⇒ Set **Start Time** to **25.2** and **End Time** to **25.5** ⇒ Click **OK**.

6. The Application Message Chart shows a single message flowing from the **FTP Server** to the Client. To show the size, rest the cursor on the message to show the tooltip. **Client Payload** is shown as 8192.

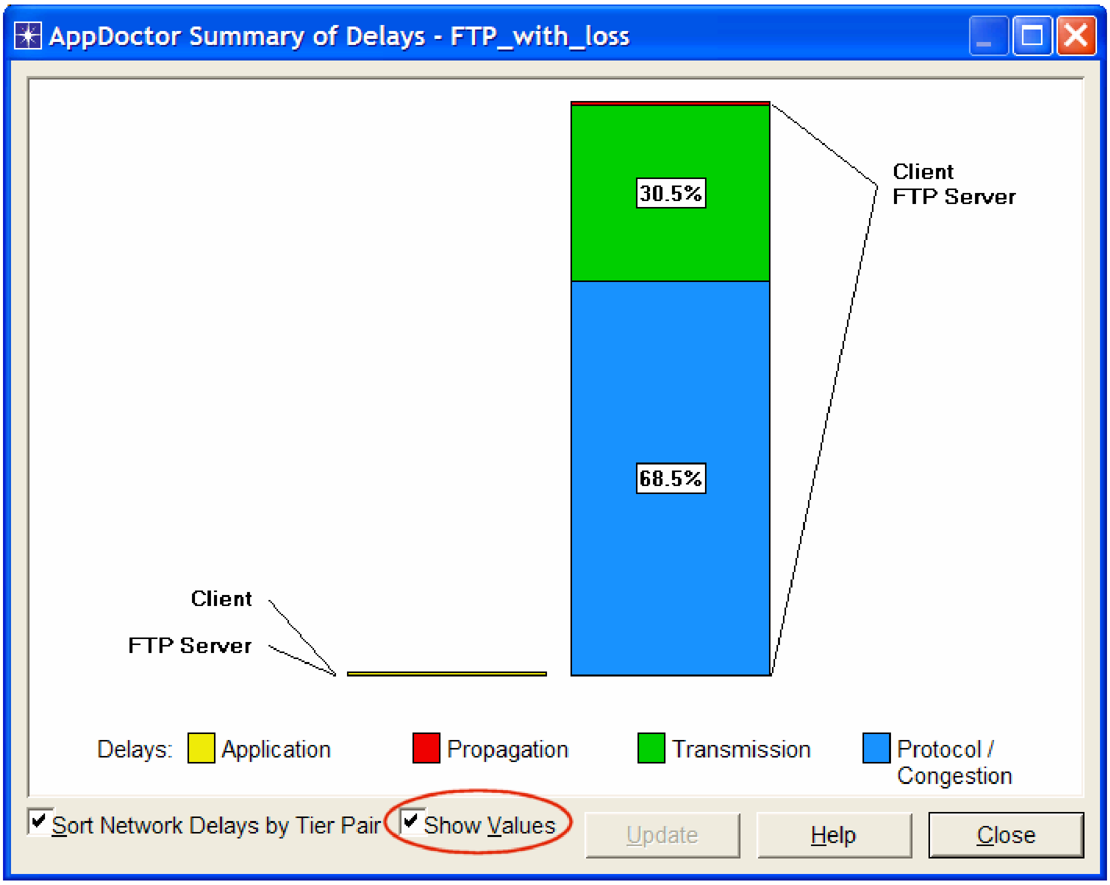
The Network Chart shows that this application message causes many packets to flow over the network. These packets are a mix of large (blue and green) packets from the FTP Server to the Client and small (red) packets from the Client to the FTP Server. As the red color indicates, these packets contain 0 bytes of application data. They are the acknowledgments sent by TCP.

13.4.3. Analyze with AppDoctor

AppDoctor's *Summary of Delays* provides insight into the root cause of the overall application delay.

1. From the **AppDoctor** menu, select **Summary of Delays** ⇒ Check the **Show Values** checkbox.

   Notice that the largest contributing factor to the application response time is protocol/congestion. Only about 30 percent of the file download time is caused by the limited bandwidth of the Frame Relay circuit (768 Kbps). Notice also that application delay (processing inside the node) by both the Client and **FTP Server** is a very minor contributing factor to the application response time.

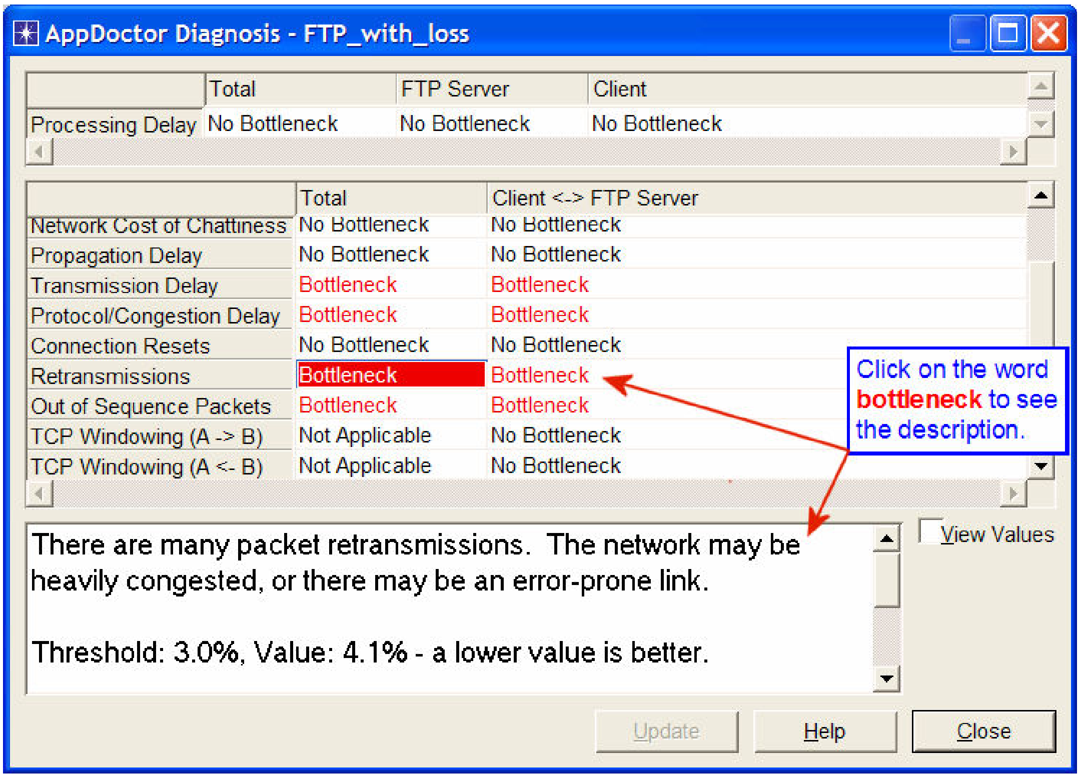


2. Close the *Summary of Delays* dialog box.

   The **Diagnosis** function of AppDoctor should give further insight into the cause of the protocol/congestion delay.

3. From the **AppDoctor** menu, select **Diagnosis**.

   The diagnosis shows four bottlenecks: transmission delay, protocol/congestion delay, retransmissions, and out of sequence packets. One factor that contributes to protocol/congestion delay is retransmissions. So it is no surprise that here, in the more detailed diagnosis, you see retransmissions listed as a bottleneck. The out of-sequence packets, also listed as a bottleneck, are a side effect of the retransmissions. Correcting that issue will probably also cure the out of sequence packets problem.



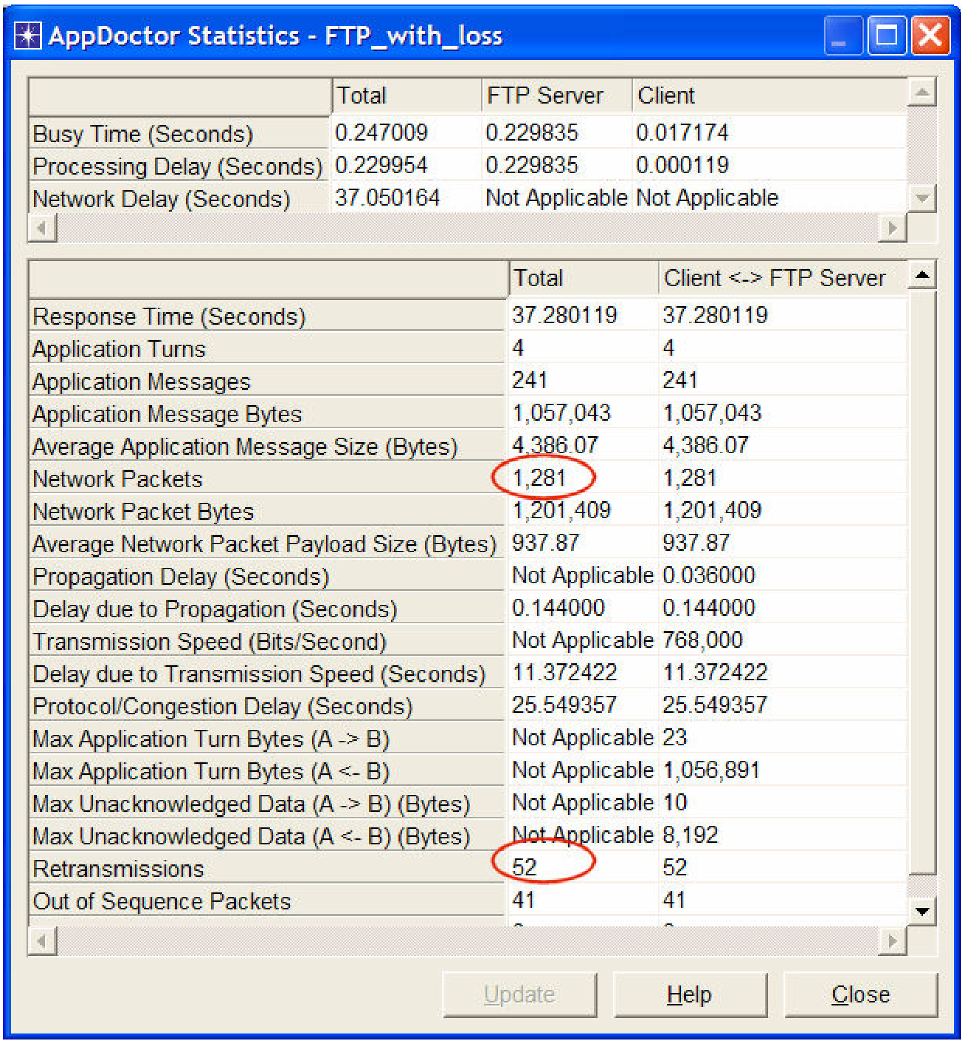
4. Close the *Diagnosis Window*

AppDoctor also provides summary statistics for the application transaction.

5. From the **AppDoctor** menu, select **Statistics**.

   Notice that 52 retransmissions occurred during a file transfer composed of 1281 packets, yielding a retransmission rate of 4%.

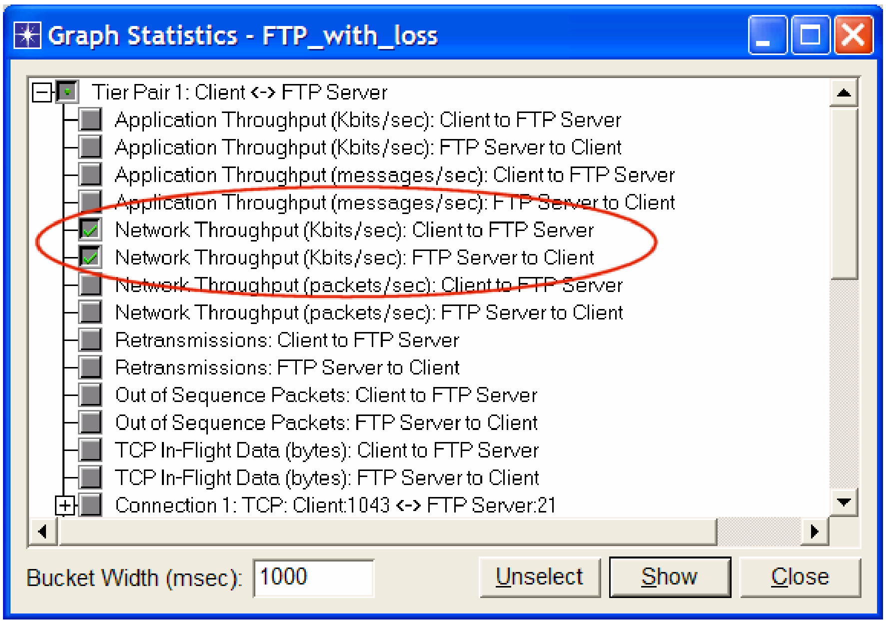
6. Close the *Statistics window*.



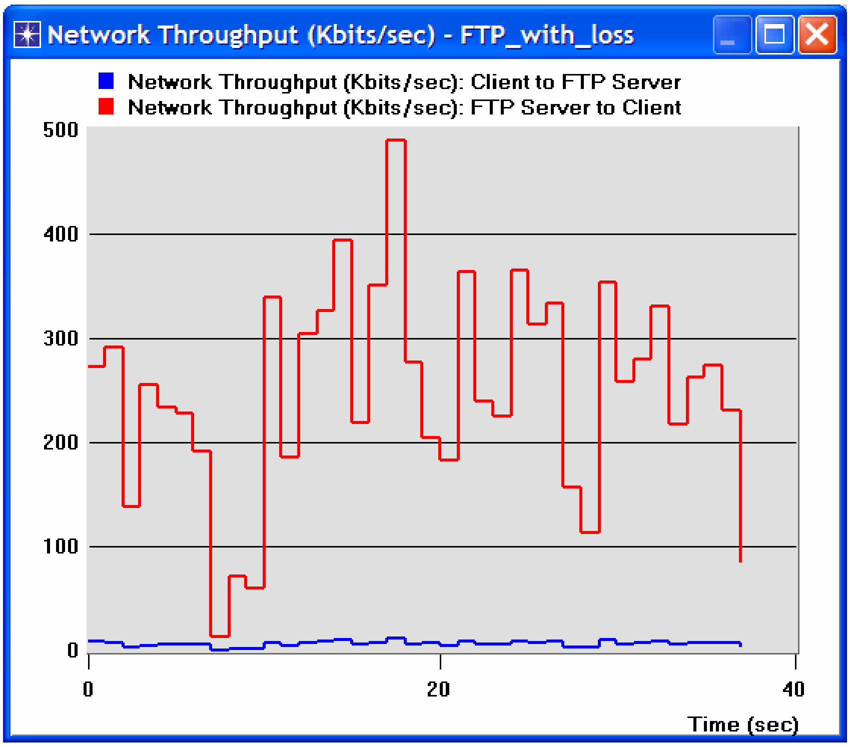
13.4.4. Examine the Statistics

To view the actual network throughput, use the **Graph Statistics** feature.

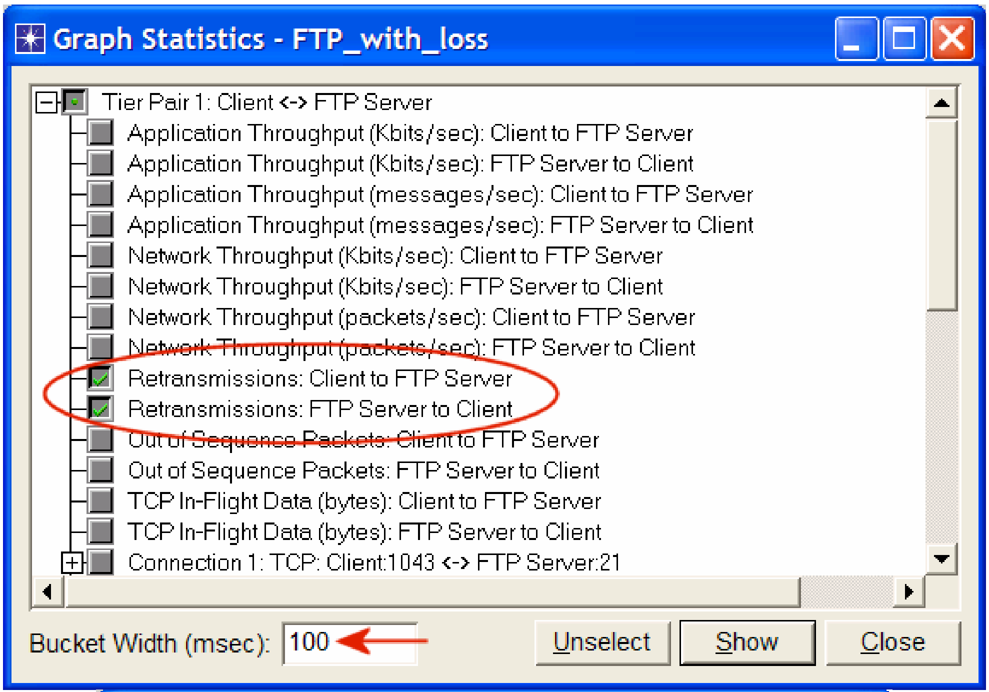
1. From the Data Exchange Chart, select **Graph Statistics** from the **Graph** menu (or click the button: ).
2. Select the two **Network Throughput** statistics that measure Kbits/sec.

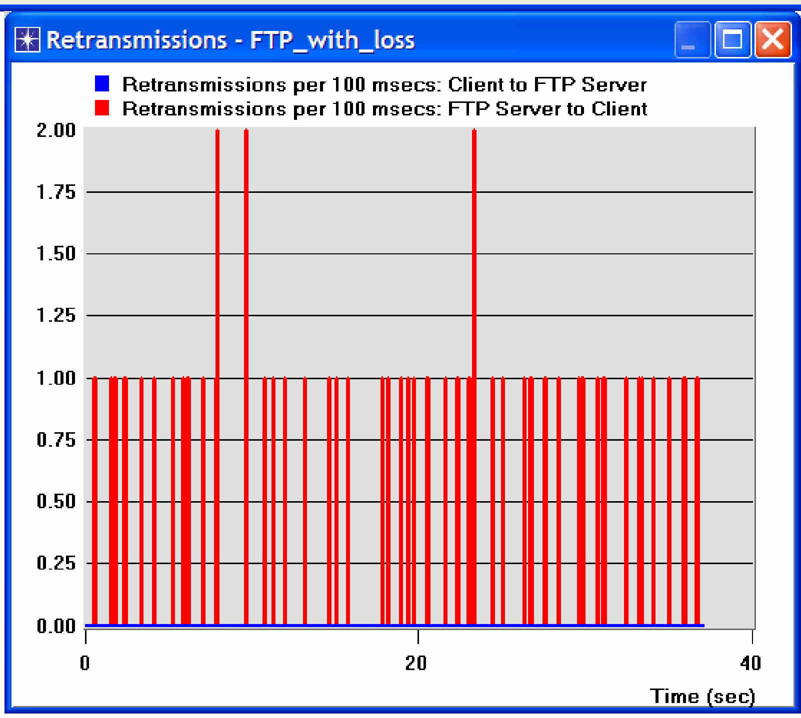


3. Click **Show.**



4. Return to the *Graph Statistics window.* ⇒ Unselect the throughput statistics and select only the two **Retransmissions** statistics ⇒ Change the **Bucket Width** to **100 ms** ⇒ Click **Show**.





ACE divides the entire tasks duration into **buckets** of time and calculate a mean of total value for each interval. The default bucket width is 1000 msec; you can change this value in the Bucket Width (msec) field of the ACE statistic hardware.

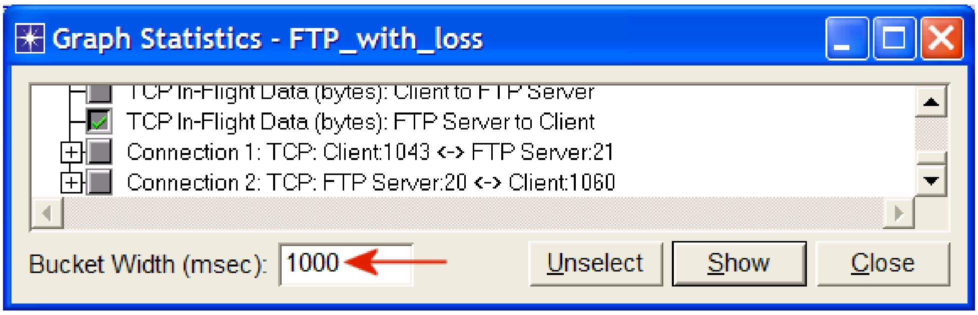
13.4.5. Ideal TCP Window Size

In TCP, rather having a fixed-size sliding window, the receiver advertises a window size to the sender. This is done using the **AdvertisedWindow** field in the TCP header. The sender is then limited to having no more than a value of **AdvertisedWindow** bytes of unacknowledged data at any given time. The receiver selects a suitable value for **AdvertisedWindow** based on the amount of memory allocated to the connection for the purpose of buffering data. This procedure is called *flow control*, and its idea is to keep the sender from overrunning the receiver's buffer.

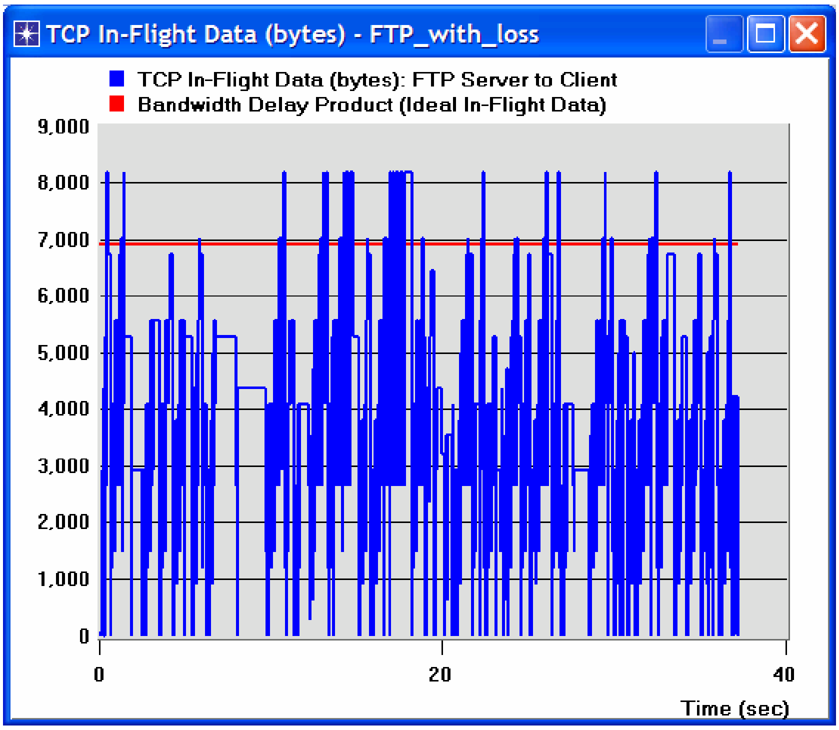
In addition, TCP maintains a new state variable for each connection, called **CongestionWindow**, which is used by the source to limit how much data it is allowed to have in transit at a given time. The congestion window is congestion control's counterpart to flow control's advertised window. It is dynamically sized by TCP in response to the congestion status of the connection.

TCP will send data only if the amount of sent-but-not-yet-acknowledged data is less than the minimum of the congestion window and the advertised window. ACE auto-calculates the optimum window size based on the bandwidth/delay product as follows:

1. Return to the Graph *Statistics window* ⇒ Select the **TCP In-Flight Data (bytes) FTP_Server to Client** statistic ⇒ Assign **1000** to the **Bucket Width (msec)**.



2. Click **Show**. From the graph, the ideal window size calculated by ACE is about 7 KB.



3. You can now close all opened graphs (delete the panel when you are asked to do that) and close the *Graph Statistics* window.

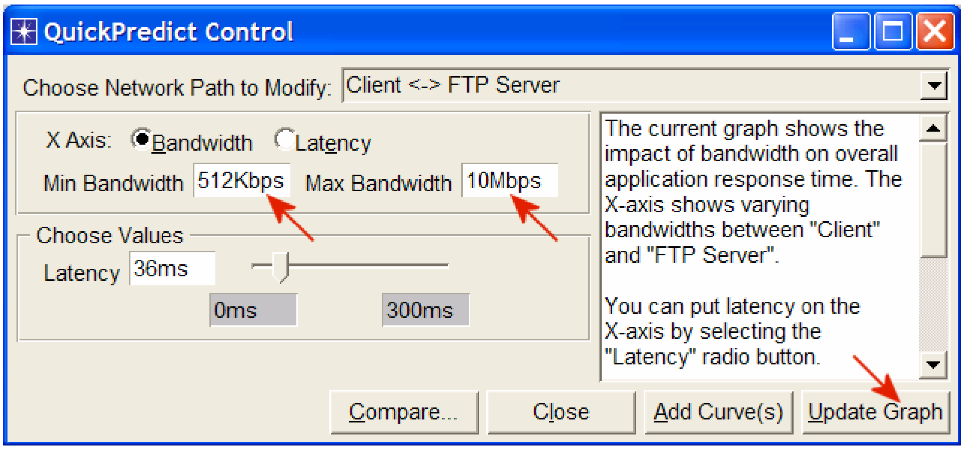
The **bandwidth-delay products** of a connection gives the "volume" of the connection - the number of bits it holds. It corresponds to how many bits the sender must retransmit before the first bit arrives at the receiver.

13.4.6. Impact of Network Bandwidth

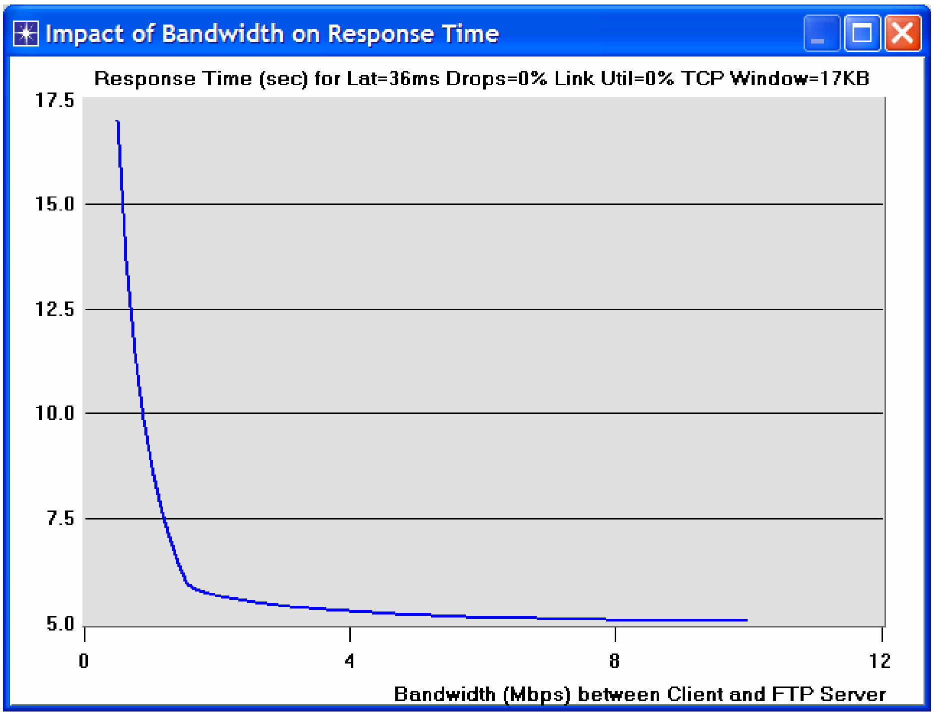
ACE **QuickPredict** enables you to study the sensitivity of an application to network conditions such as bandwidth and latency.

1. Click on the **QuickPredict** button: .

2. In the *QuickPredict Control* dialog box assign **512 Kbps** to the **Min Bandwidth** field and **10 Mbps** to the **Max Bandwidth** field ⇒ Click the **Update Graph** button.



3. The resulting graph should resemble the following one:



4. Close the graph and the *QuickPredict Control* dialog box.

13.4.7. Deploy an Application

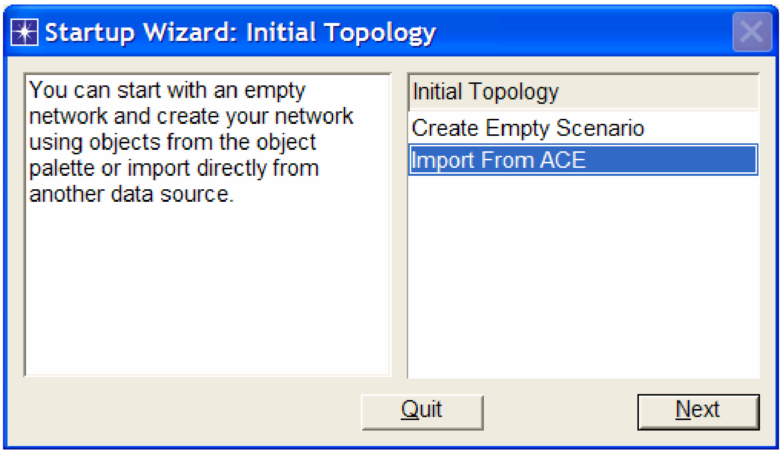
OPNET IT Guru can be used to perform predictive studies of applications that are characterized in ACE. ACE uses the trace files to create application fingerprints that characterize the data exchange between tiers. From these fingerprints, a simulation can show how the application will behave under different conditions. For example, the ACE topology wizard can be used to build a network model from the ACE file of this lab, **FTP_with_loss** to answer the following question: What will the performance of the FTP application be when deployed to 100 simultaneous users over an IP network?

Follow the following steps to answer the above question:

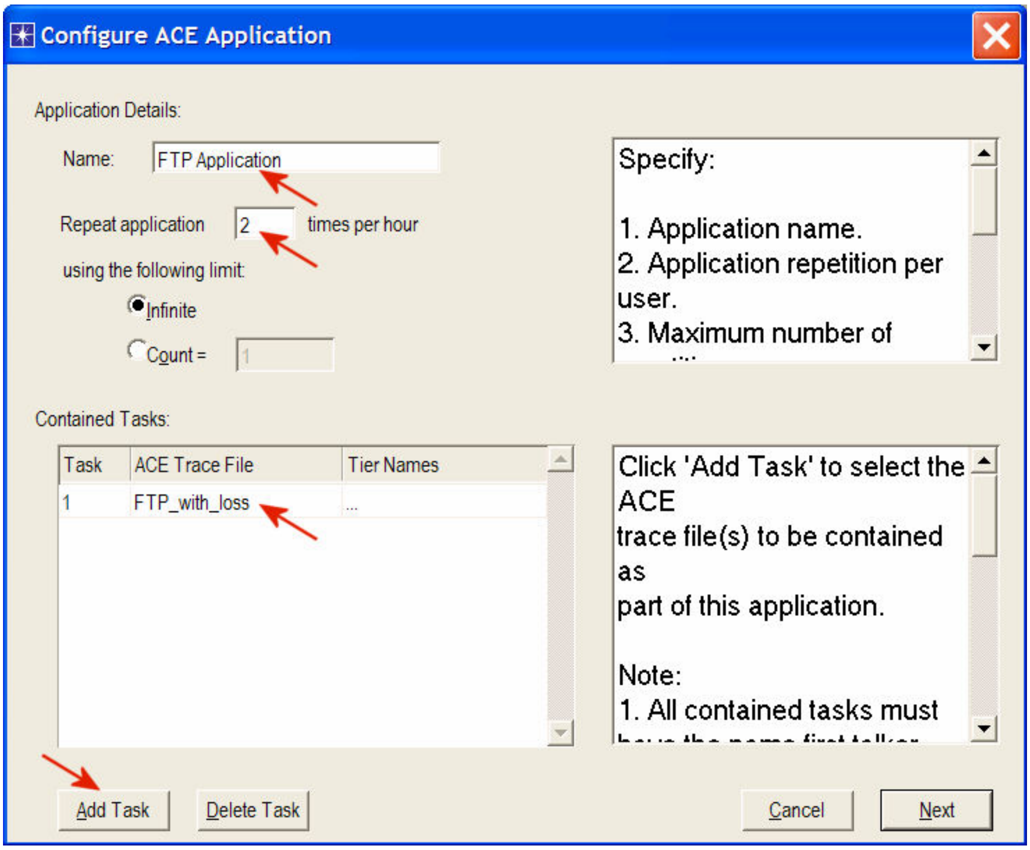
1. From the IT Guru main window, select **File** ⇒ **New** ⇒ Select **Project** from the pull-down menu ⇒ Click **OK**.

2. Name the project **<your initials>_FTP**, and the scenario **ManyUsers** ⇒ Click **OK**.

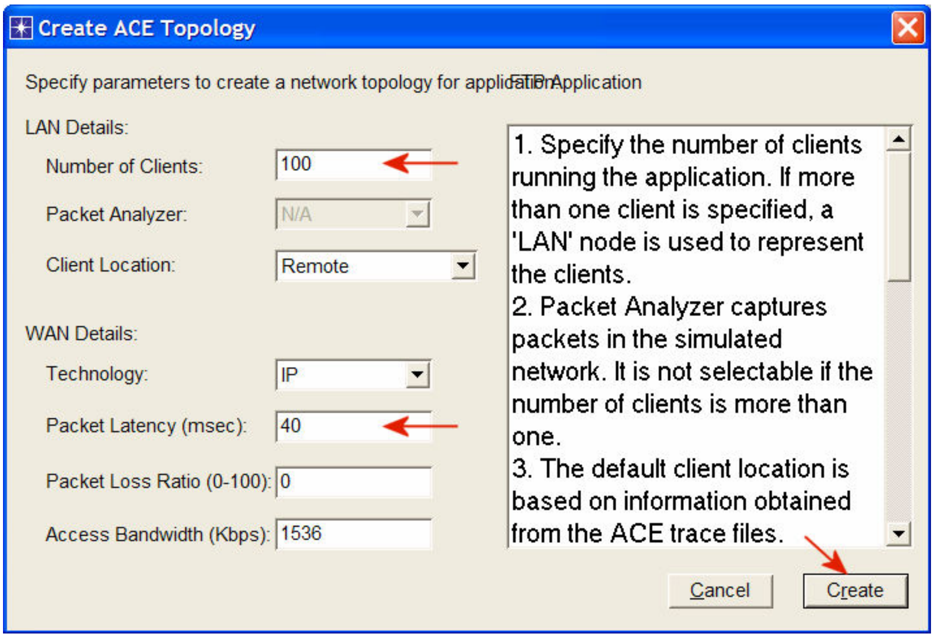
3. In the *Startup Wizard*, select **Import from ACE** ⇒ Click **Next**.



4. The *Configure ACE Application* dialog box appears.
   i. Set the **Name** field to **FTP Application.**
   ii. Set the **Repeat** application field to **2.** This field controls how many times a user executes the application per hour.
   iii. Leave the limit at the default value, **Infinite**.
   iv. Click on **Add Task** ⇒ In the **Contained Tasks** table, click on the word **Specify** ... ⇒ Select **FTP_with_loss** from the pull-down menu.
   v. Click **Next**

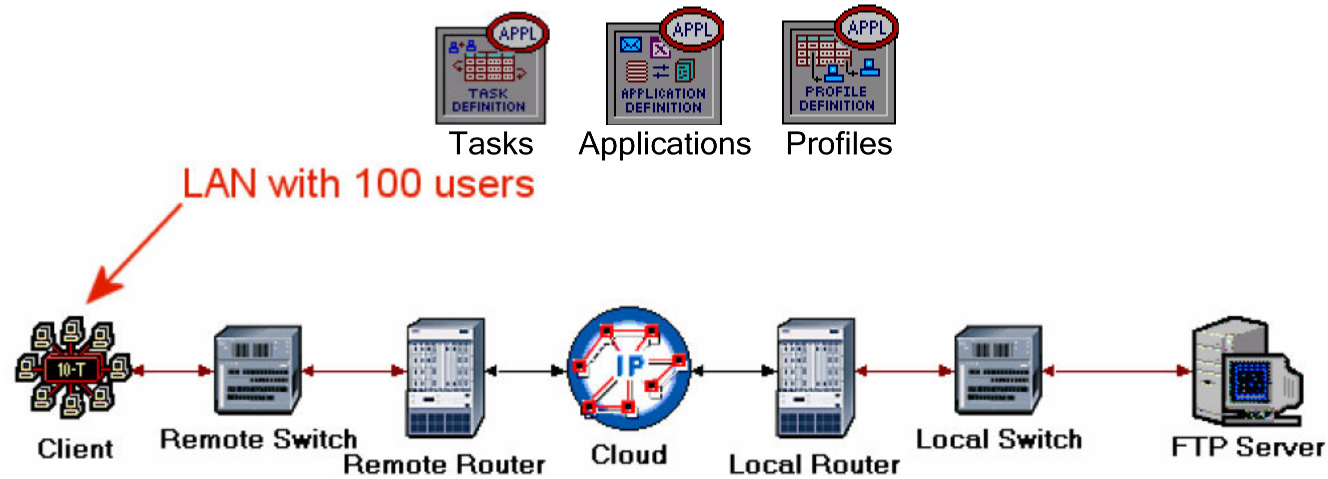


5. The *Create ACE Topology* dialog box appears. Set **Number of Clients** to **100** and set **Packet Latency** to **40.** Leave all other settings at the default values.
6. Click **Create.**



7. Select **File** ⇒ **Save** ⇒ Click **OK** to save the project.

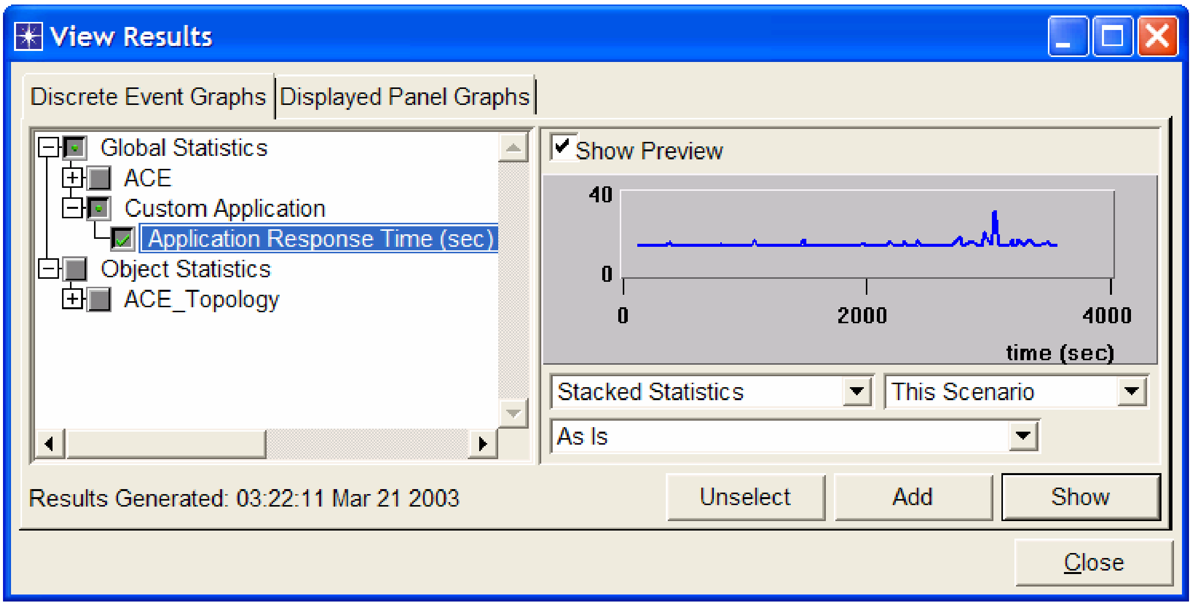
   The ACE Wizard creates a topology similar to the one shown. The **Tasks, Applications,** and **Profiles** objects have all been configured according to the trace files and the entries you made in the ACE Wizard. You can customize them further.



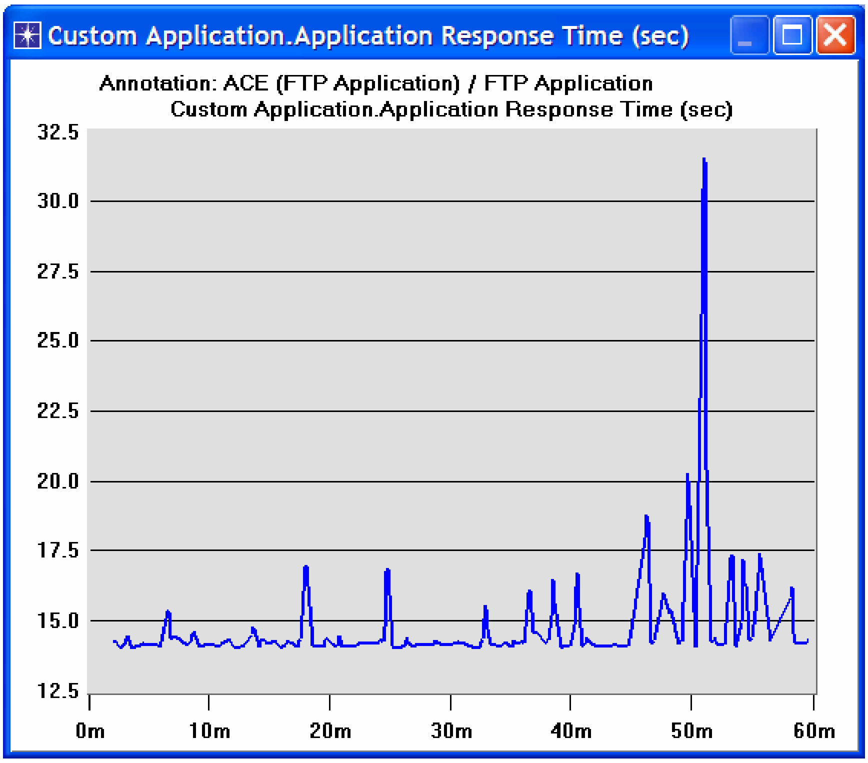
13.4.7.1. Run the Simulation and View the Results:

Now that the topology is created, you can run the simulation.

1. Click on the **Configure/Run Simulation** action button .
2. Use the default values. Click **Run.** Depending on the speed of your processor, this may take several minutes to complete.
3. Close the dialog box when the simulation completes. ⇒ Save your project.
4. Select **View Results** from the **Results** menu ⇒ Expand the **Custom Application** hierarchy ⇒ Select the **Application Response Time (sec)** statistic.



5. Click **Show**. The resulting, graph should resemble the following:



13.5. *Further readings*

- File Transfer Protocol (FTP): IETF RFC number 959 (www.ietf.org/rfc.html).

13.6. *Exercises*

1) Explain why the Client to FTP Server messages are mainly 0-byte messages?
2) Utilizing the AppDoctor's Summary of Delays, what is the effect of each of the following upgrades on the FTP download time?
   a. Server upgrade
   b. Bandwidth upgrade
   c. Protocol(s) upgrade

3) How do retransmissions contribute to protocol/congestion delay? Explain why "out of sequence" packets are constitute a side effect of retransmissions.
4) Which protocol is responsible for the retransmission, IP, TCP, or FTP? Explain.
5) In the **Network Throughput** graph, the throughput from the **FTP Server** to the Client has an average value of about 300 Kbps and has a spike to about 500 Kbps. But the Frame Relay circuit has an available bandwidth of 768 Kbps. Explain why the throughput is not close to the available bandwidth.
6) Explain how the TCP in-flight data is used as an indicator of the TCP window size and how the bandwidth-delay product of the connection is used as an indicator of the ideal window size.
7) Comment on the graph we received that shows the relation between the network bandwidth and the FTP application response time. Why does the response time look unaffected by increasing the bandwidth beyond a specific point?
8) In the Deploy an Application section, a network model with multiple users was created based on the ACE file, **FTP_with_loss**. Duplicate the created scenario to create a new one with the name **Q8_ManyUsers_ExistingTraffic**. In this new scenario add an "existing" traffic of 80% load in the network. Examine how the existing traffic affects the FTP application's response time. Note: A simple way to simulate the existing traffic is to apply background utilization traffic of 80% to the link between the **Remote Router** and the **IP Cloud**.

13.7. *Lab Report*

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

14. Laboratory - Wireless Local Area Network (Medium Access Control for Wirelessly Connected Stations)

14.1. *Objective*

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

14.2. *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 the 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 virtual carrier-sense mechanism to determine the state of the medium. This virtual mechanism is implemented by means of the network allocation vector (NAV). The NAV 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 RTS (request to send) and CTS (clear to send) frames with the receiving station. The effect of RTS and CTS frames will be studied in the following 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 poll received from the PC. Such stations are called CF-Pollable stations. The PCF requires control to be gained of the medium by the PC. To gain such control, the PC utilizes the Beacon management frames to set the network allocation vector (NAV) in the network stations. As 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 (CFP). 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 burst 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).

14.3. *Prelab Activities*

- Read section 2.8.2 from *"Computer Networks: A Systems Approach"*, 4th *Edition*.

14.4. *Procedure*

14.4.1. Create a New Project

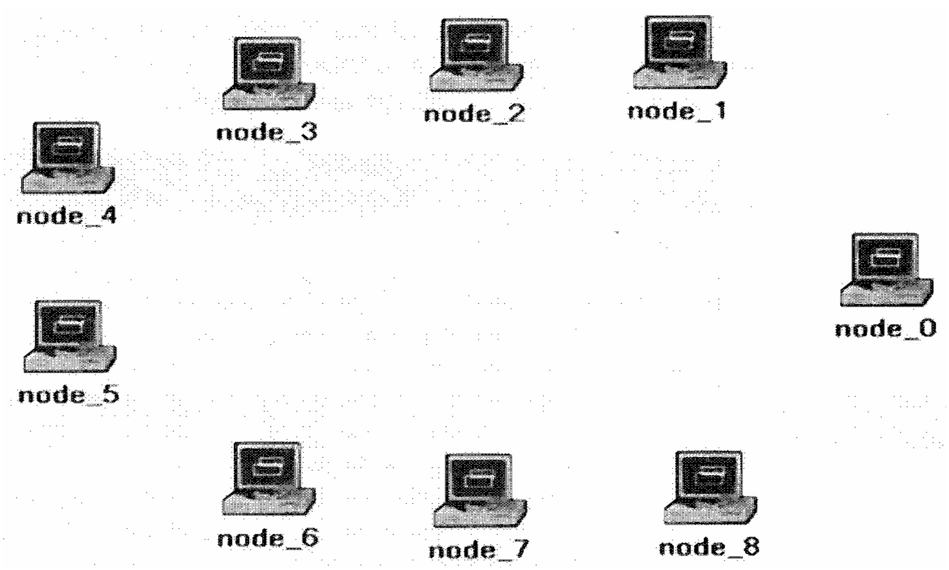
To create a new project for the Ethernet network:

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 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**.

14.4.2. 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 following objects from the palette: 9 **wlan_station_adv (fix)**.
   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.



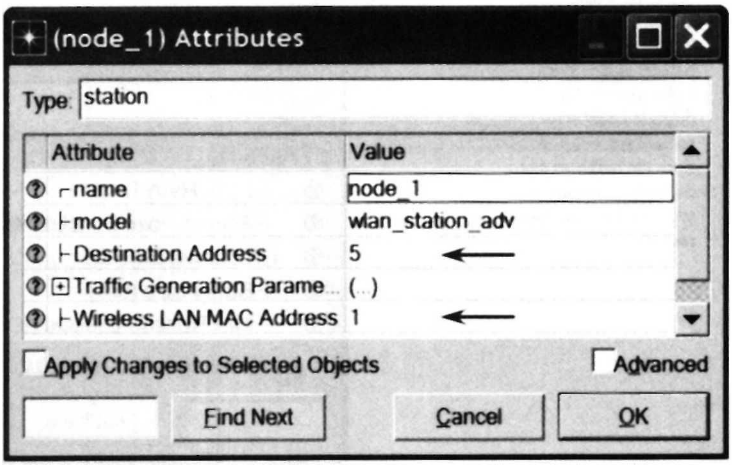
14.4.2.1. Configure the wireless nodes:

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.**

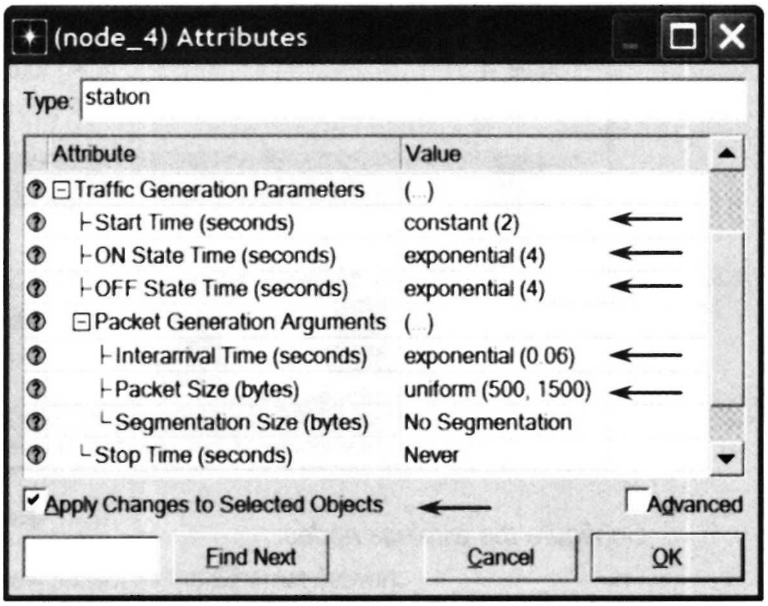
   - The following figure shows the values assigned to the **Destination Address** and **Wireless LAN MAC Address** attributes for **node_1**.

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



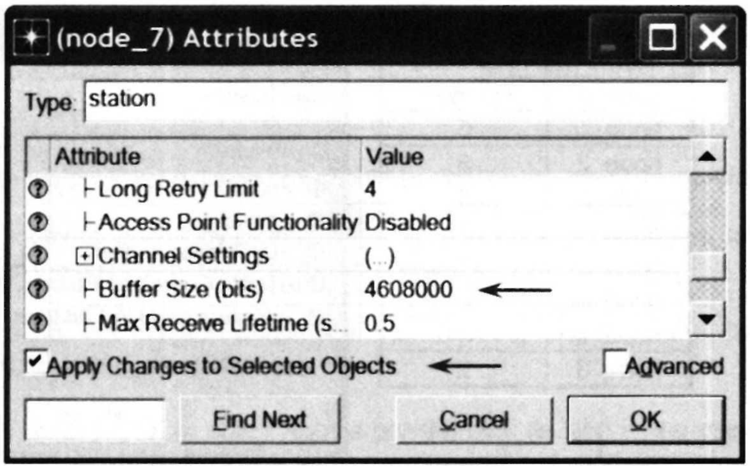
14.4.2.2. Traffic Generation Parameters:

1. Select all the 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 (i.e., **node_1** to **node_8**) ⇒ **Edit Attributes** ⇒ Check the **Apply Changes to Selected Objects** check box.
2. Expand the hierarchies of the **Traffic Generation Parameters** and the **Packet Generation Arguments** attributes. ⇒ Edit the attributes to match the values shown in the following figure ⇒ Click **OK**.



3. Select all the 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**.



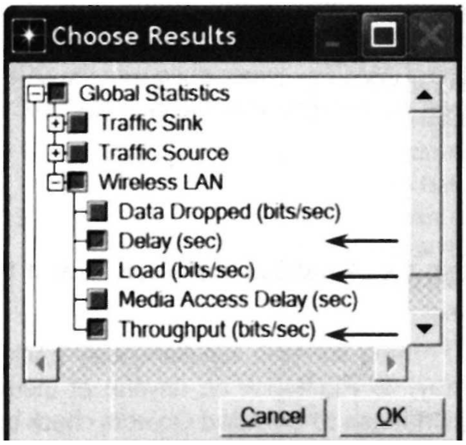
5. Right-click on **node_0** ⇒ **Edit Attributes** ⇒ Expand the **Wireless LAN Parameters** hierarchy and set the **Access Point Functionality** to **Enabled.** ⇒ Click **OK.**

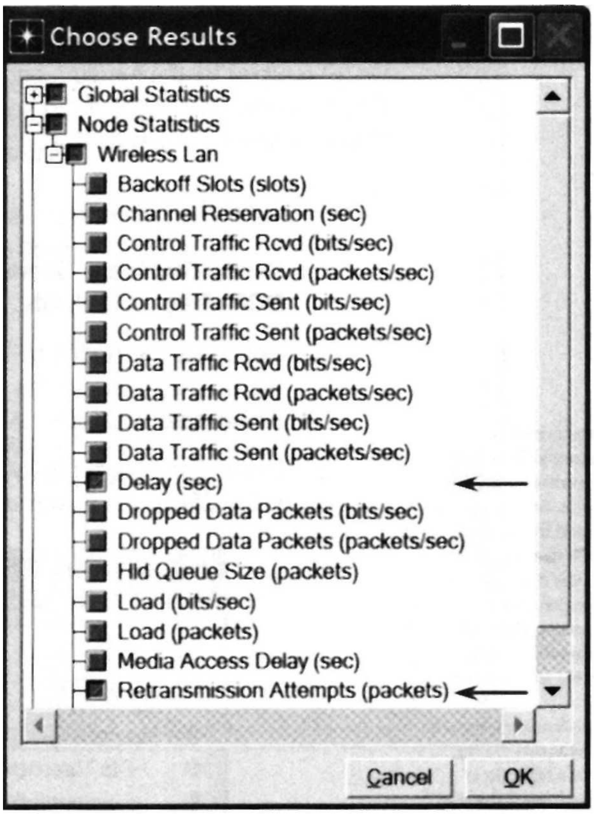
Buffer sizes specifies the maximum size of the higher layer data buffer limit is reached, the data packets arrived from higher layer will be discarded until some packets are removed from the buffer so that the buffer has some free space to store these new packets.

14.4.3. 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 following five statistics:





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

14.4.4. Configure the Simulation

Here we will configure the simulation parameters:

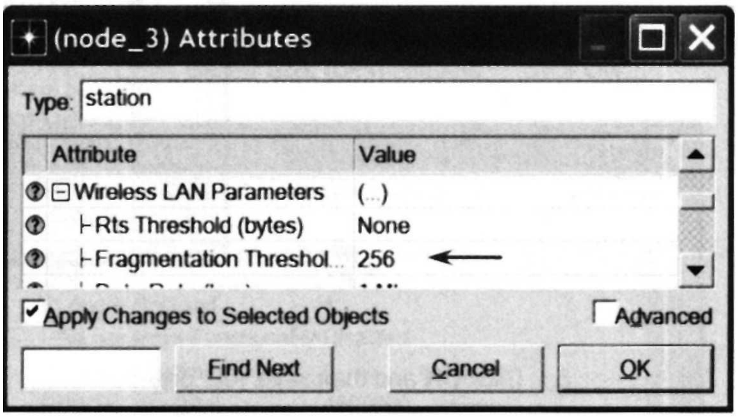
3. Click on  and the *Configure Simulation* window should appear.
4. Set the duration to be **10.0 minutes**.
5. Click **OK** and then save your project.

14.4.5. 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 medium access control (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.

14.4.5.1. 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 (click on all of them while holding the **Shift** key) ⇒ Right-click on anyone 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.**

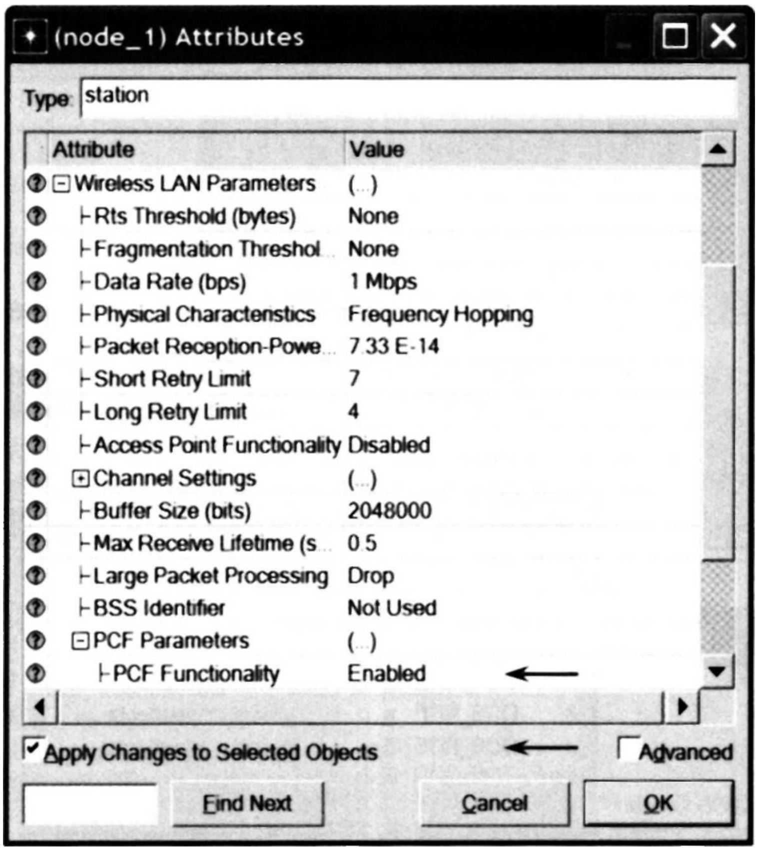


4. Right-click on **node_0** ⇒ **Edit Attributes** ⇒ Expand the **Wireless LAN Parameters** hierarchy and set the **Access Point Functionality** to **Enabled**. ⇒ Click **OK**.

Fragmentation Threshold specifies the fragmentation threshold in bytes. Any data packet received from 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 the IEEE 802.12 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.

14.4.5.2. The DCF_PCF Scenario:

1. Switch to the **DCF** scenario, select **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 anyone 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**.
5. Click **OK** and save your project.

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

14.4.5.3. The DCF_PCF_Frag Scenario:

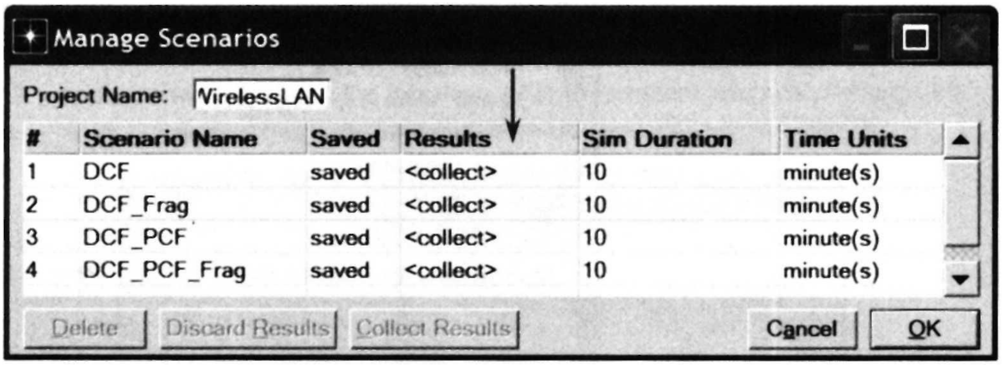
1. Switch to the **DCF_Frag** scenario, select **Duplicate Scenario** from the **Scenarios** menu and give it the name **DCF_PCF_Frag** ⇒ Click **OK** ⇒ Save your project.
2. Select **node_0**, **node_1**, **node_3**, **node_5**, and **node_7** in the **DCF_PCF_Frag** scenario simultaneously (click on these nodes of them white holding the **Shift** key) ⇒ Right-click on anyone 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**.

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

14.4.6. 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.

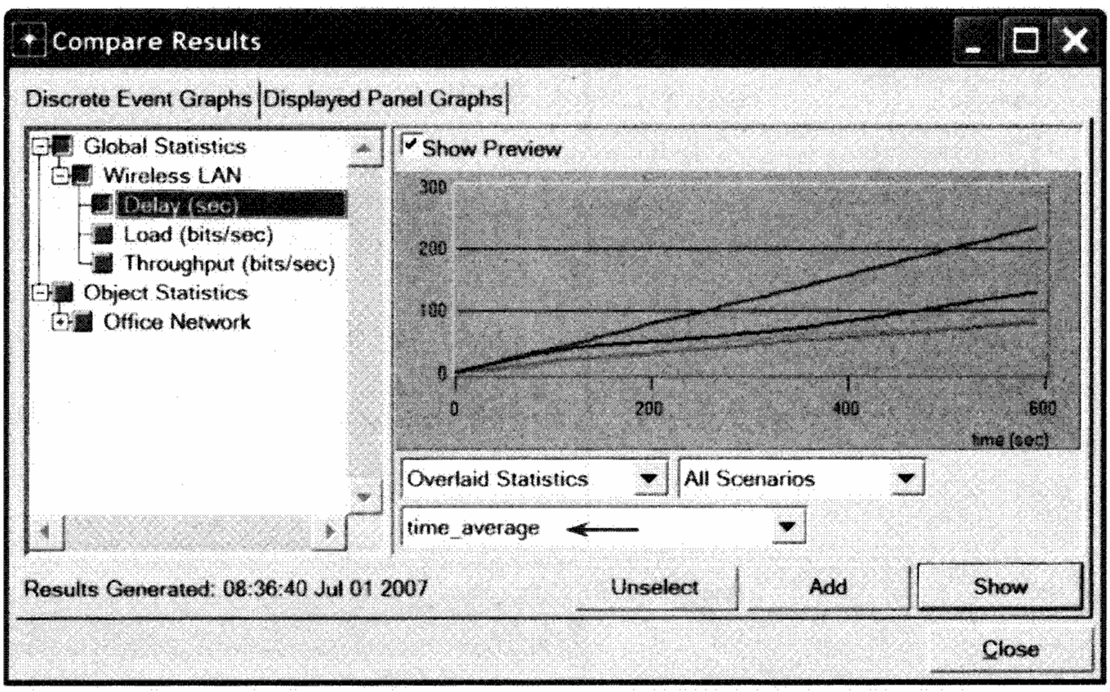


3. Click **OK** to run the four simulations. Depending on the speed of your processor, this may take several seconds to complete.
4. After the simulation of the four scenarios complete, click **Close** and then save your project.

14.4.7. View the Results

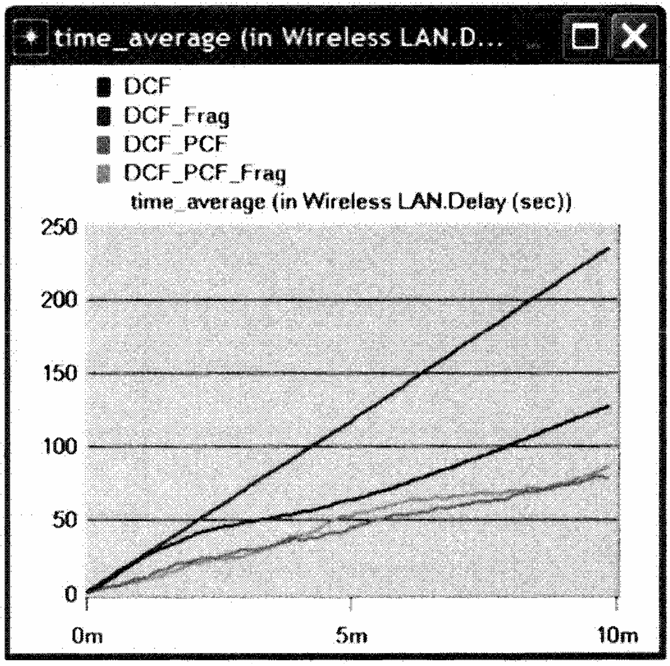
To view and analyze the Results (*Note:* Actual results will vary slightly based on the actual node positioning in the project):

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.



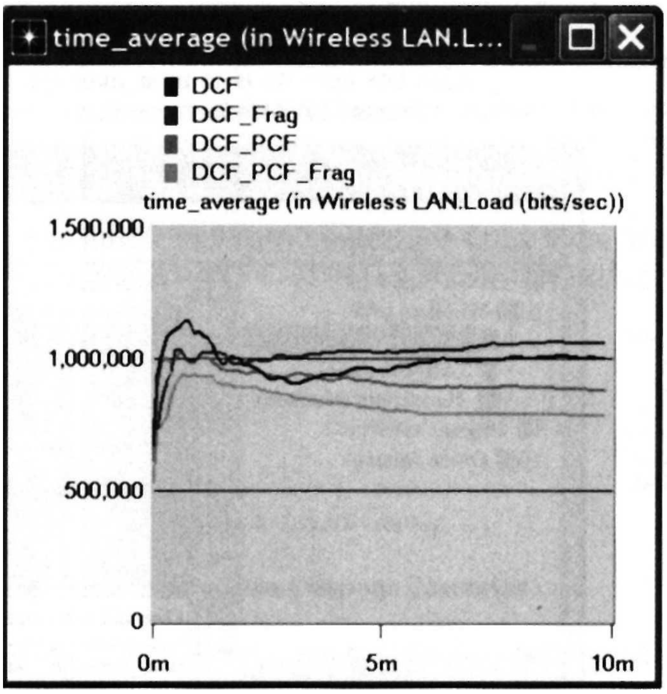
time_average is the average value over time of the values generated during the collection window. This average is performed assuming a "sample and hold" behavior of the data set (i.e., each value is weighted by the amount of time separating it from the following update and the sum of all the weighted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

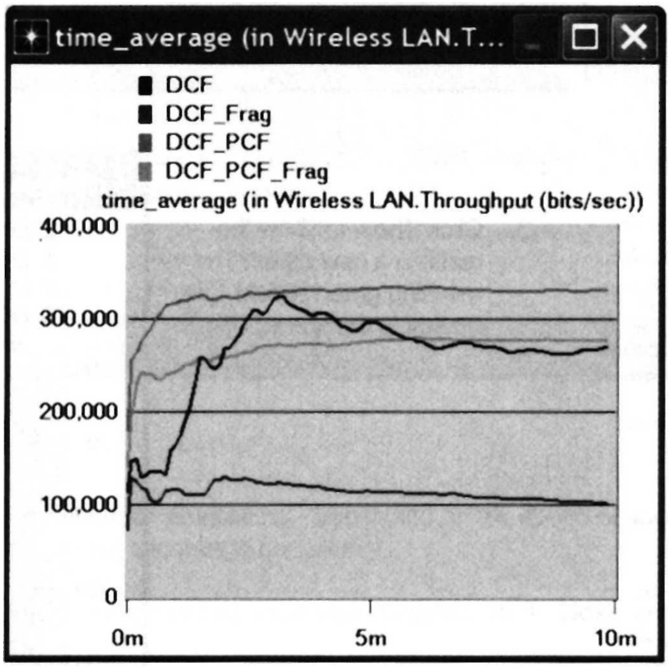


Delay represents the end-to-end delay of all the packets received by the wireless LAN MACs of all WLAN nodes in the network and forwarded to the higher layer. The delay includes medium access delay at the source MAC, reception of all the fragments individually, and transfer of the frames via AP, if access 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.

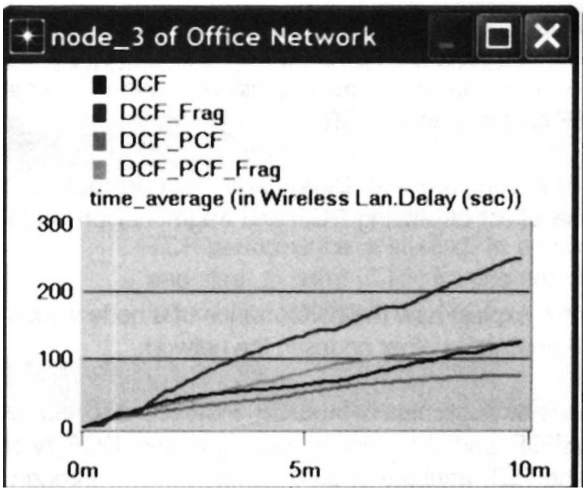


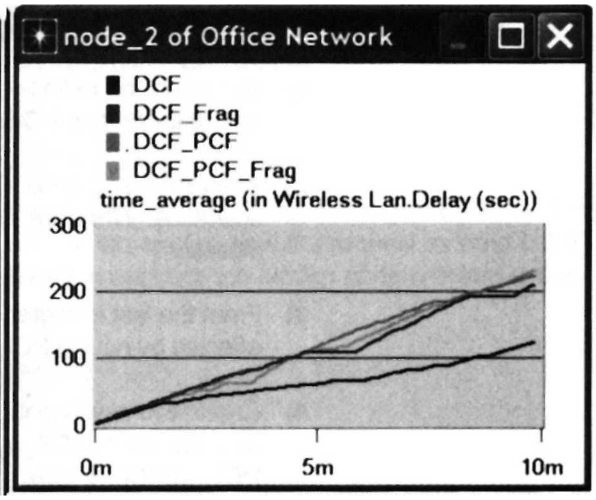
Load represents the total load (in bits/sec) submitted to wireless LAN layers by all other WLAN nodes of the network. The statistic does not include the bits of the higher layer packets that are dropped by WLAN MACs upon arrival and not considered for transmission due to, for example, insufficient space left on the higher layer packet buffer of the MAC.



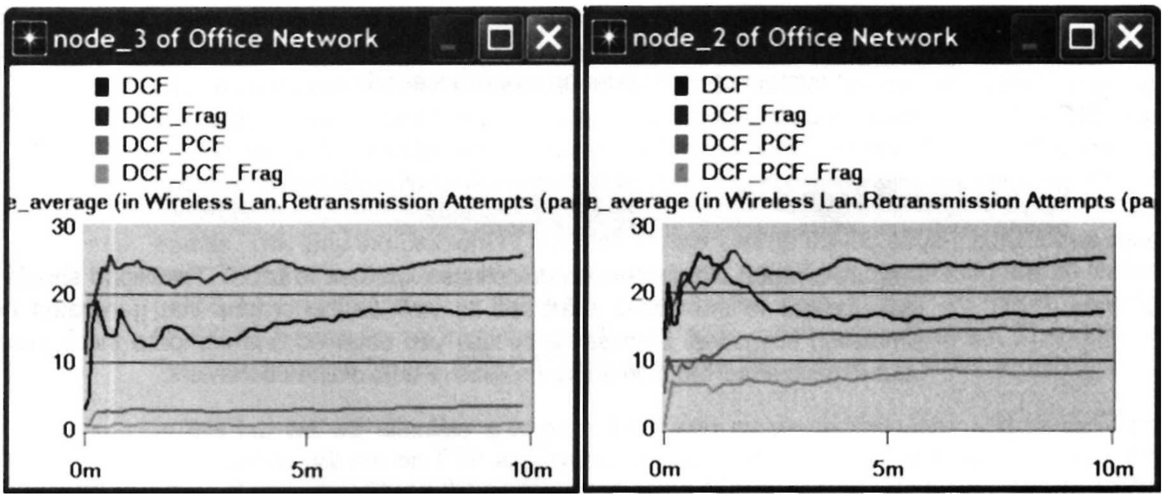
Throughput represents the total number of bits (in bits/sec) forwarded from wireless LAN layers to higher layers in all WLAN nodes of the network.

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 a graphs and the *Compare Results* dialog box ⇒ Save your project.

14.5. *Further readings*

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

14.6. *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 effect 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 8 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. Re-run 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.

14.7. *Lab Report*

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

15. Laboratory - Mobile Wireless Network (A Wireless Local Area Network with Mobile Stations)

15.1. *Objective*

This lab simulates mobility in wireless local area network. The effect of mobility on the TCP performance is studied. In addition, the lab studies how the request to send (RTS) and clear to send (CTS) frames are utilized in avoiding the hidden node problem usually induced by mobility in WLAN.

15.2. *Overview*

One of the requirements of the IEEE 802.11 standard is to handle mobile stations in wireless local area networks. Mobile stations are defined as the stations that access the LAN while in motion. IEEE 802.11 handles station mobility within the MAC sublayer and hence such mobility is hidden from the higher layers in the network. However the disconnection and reconnection events induced by mobility in WLAN significantly affect the performance of higher layer protocols such as TCP. For example TCP interprets disconnection due to mobility as congestion and hence it multiplicatively decreases its congestion window size. After reconnection, TCP takes unnecessary longer time to recover the congestion window to a size that matches the available bandwidth.

IEEE 802.11 utilizes the request to send (RTS) and clear to send (CTS) frames in various circumstances to further minimize collisions. RTS and CTS are especially useful in solving the hidden node problem in WLANs that have mobile stations. Exchanging the RTS and CTS between the sender and the receiver informs nearby stations that a transmission is about to begin. Duration information in RTS/CTS frames are used to set the network allocation vector (NAV) in all stations that are within the reception range of the RTS/CTS frames. This way the problem of a hidden sender can be solved as any station that sees the CTS frame knows that it is close to the receiver, and therefore cannot transmit for the period of time indicated in the NAV. If transmitted data frames are short, sending RTS/CTS frames is not recommended as it adds overhead inefficiency. Therefore, a threshold is defined to use RTS/CTS only on frames longer than a specified length.

In this lab we will simulate a wireless LAN with mobile workstations and server. The workstations will run an FTP application to upload files to the server. We will study the effect of node mobility on the performance of the TCP connection for the FTP session. We will study also the role of the request to send (RTS) and clear to send (CTS) frames in avoiding the hidden node problem usually induced by mobility in wireless LAN.

15.3. *Prelab Activities*

- Read sections 2.8.2 and 4.2.5 from ***"Computer Networks: A Systems Approach"*** 4th ***Edition.***
  - Wireless Network and Multiple Access with Collision Avoidance

15.4. *Procedure*

15.4.1. Create a New Project

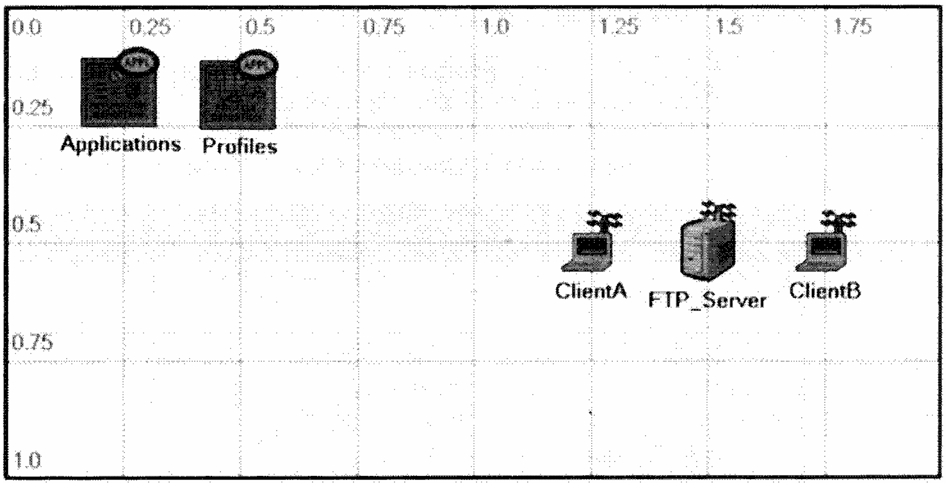
1. Start **OPNET IT Guru Academic Edition** ⇒ Choose **New** from the **File** menu.

2. Select **Project** and Click **OK** ⇒ Name the project **<your initials>_MobileWLAN** and the scenario **Mobile_noRTSCTS** ⇒ Click **OK**.
3. In the *Startup Wizard: Initial Topology* dialog box, make sure that **Create Empty Scenario** is selected ⇒ Click **Next** ⇒ Select **Campus** from the *Network Scale* list ⇒ Click **Next** ⇒ Make sure that Kilometer is the unit chosen for the **Size** and then assign 2 and 1 to the **X Span** and **Y Span** respectively ⇒ Click **Next** twice ⇒ Click **OK**.

15.4.2. Create and Configure the Network

15.4.2.1. 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 **wireless_lan** is selected from the pull-down menu on the object palette.
2. Add to the project workspace the following objects from the palette: **Application Config**, **Profile Config**, two **wlan_wkstn (mob)**, and one **wlan_server (mob)**.
   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. Arrange and rename the objects you added as shown:



5. Position the workstations and the server according to the x and y positions shown in the following table:
   a. To position an object: Right-click on the object ⇒ **Advanced Edit Attributes** ⇒ Edit the **x position** and **y position** attributes.

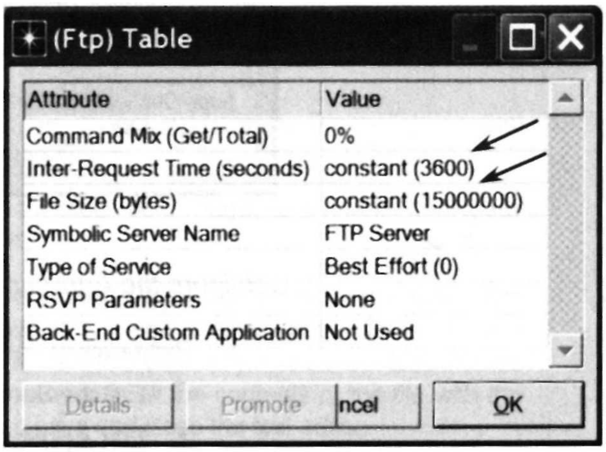
Node	x position	y position
ClientA	1.25	0.5
FTP_Server	1.5	0.5
ClientB	1.75	0.5

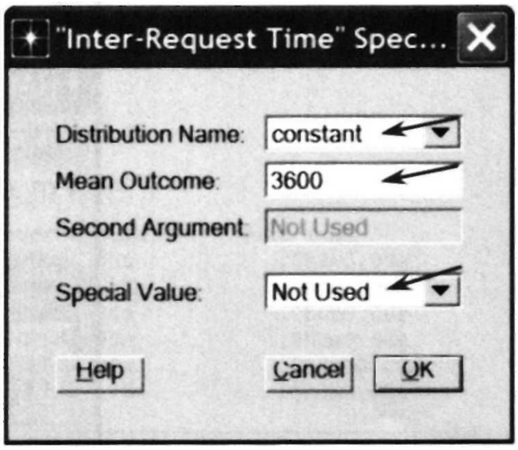
0% for the "Command Mix (Get/Total)" attribute means all the FTP sessions will be only "Serial" from the clients to the server.

15.4.2.2. Configure the Applications:

1. Right-click on the **Applications** node ⇒ **Edit Attributes** ⇒ Expand the **Application Definitions** attribute and set **rows** to **1** ⇒ Expand the new row ⇒ Name the row **FTP_Application**.

   i. Expand the **Description** hierarchy ⇒ Edit the **FTP** row as shown (you will need to set the **Special Value** to **Not Used** while editing the shown attributes):



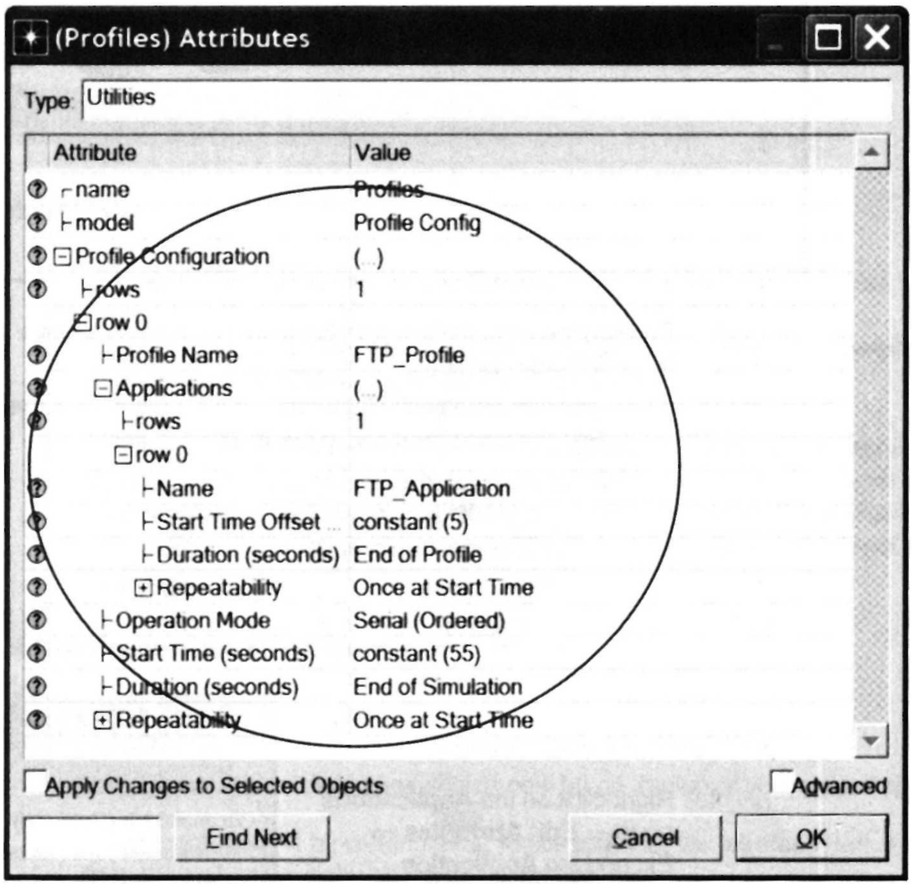


2. Click **OK** twice and then save your project.

15.4.2.3. Configure the Profiles:

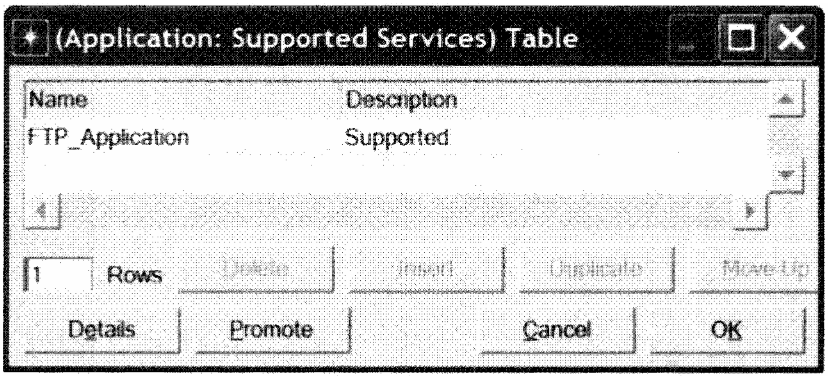
1. Right-click on the **Profiles** node ⇒ **Edit Attributes** ⇒ Expand the **Profile Configuration** attribute and set **rows** to **1**.

   i. Name and set the attributes of **row 0** as shown ⇒ Click **OK**.

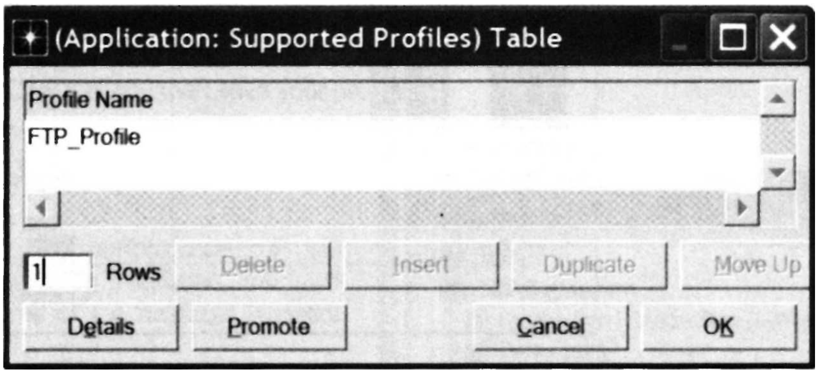


15.4.2.4. Configure the Applications in the Server and Clients:

1. Right-click on the **FTP_Server** node ⇒ **Edit Attributes:**
   i. Edit the **Server Address** attribute ⇒ Assign the value **FTP_Server** to it.
   ii. Edit **Application: Supported Services** ⇒ Set **rows** to **1** ⇒ Set **Name** to **FTP_Application** ⇒ Click **OK** twice.



2. Select both **ClientA** and **ClientB** in the network simultaneously (click on both of them while holding the **Shift** key) ⇒ Right-click on one of them ⇒ **Edit Attributes** ⇒ Check the **Apply Changes to Selected Objects** check box:
   i. Expand the **Application: Supported Profiles** hierarchy ⇒ Set **rows** to **1** ⇒ Set **Profile Name** to **FTP_Profile** as shown ⇒ Click **OK**.



   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 **FTP_Server** to the **Name** column.

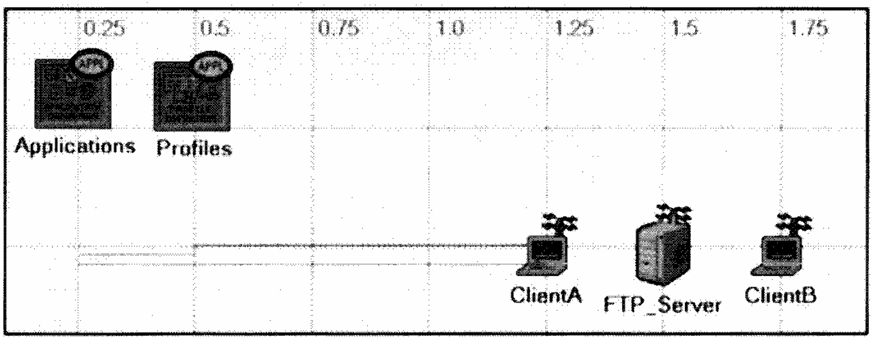
3. Click **OK** three times and then save your project.

15.4.2.5. Configure the Trajectory:

1. Right-click on **ClientA** ⇒ **Edit Attributes** ⇒ Assign **trajectory_1** to the **trajectory** attribute ⇒ Click **OK**.
2. A green trajectory will appear on the project workspace. Right-click on that trajectory and select **Edit Trajectory**.
3. In the **Edit Trajectory** *Information* dialog box, name the trajectory **<your initials>_left_trajectory** ⇒ Click **OK**.
4. From the **Edit** menu, choose **Preferences**. Check the value of the **mod_dirs** attribute. A list of directories will appear. The first directory in the list is where a trajectory file with the name **<your initials>_left_trajectory.trj** is saved. Edit that file using any text editor (e.g., Notepad). Replace all the contents of the file with the info shown in the following figure then save and close the text editor.

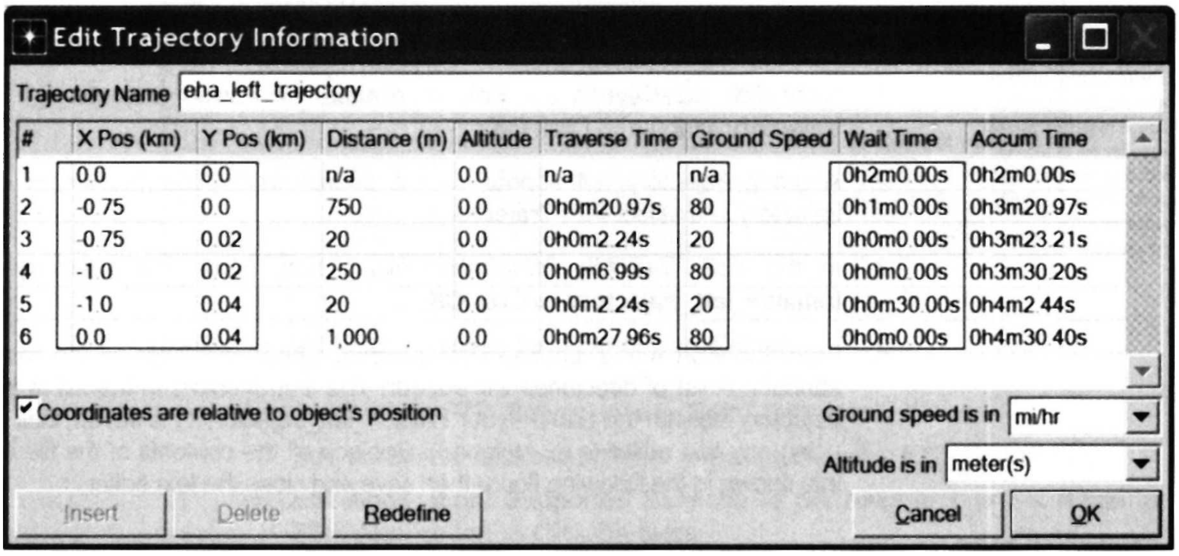
```
Version: 2
Position_Unit: Kilometers
Altitude_Unit: Meters
Coordinate_Method: relative
Altitude_Method: absolute
locale: English_United States.1252
Coordinate_Count: 6
# X Position        Y Position          Altitude            Traverse Time       Wait Time
0                   ,0                  ,0                  ,0h0m0.00s          ,0h2m0.00s
-0.75               ,0                  ,0                  ,0h0m20.97s         ,0h1m0.00s
-0.75               ,0.02               ,0                  ,0h0m2.24s          ,0h0m0.00s
-1                  ,0.02               ,0                  ,0h0m6.99s          ,0h0m0.00s
-1                  ,0.04               ,0                  ,0h0m2.24s          ,0h0m30.00s
0                   ,0.04               ,0                  ,0h0m27.96s         ,0h0m0.00s
```

5. Right-click on **ClientA** ⇒ **Edit Attributes** ⇒ Assign **<your initials>_left_trajectory** to the **trajectory** attribute ⇒ Click **OK**.
6. The new trajectory should look exactly like the following one. Right-click on the trajectory and select **Edit Trajectory**.



7. In the *Edit Trajectory* Information dialog box, verify that the trajectory info matches the values shown in the following figure:

Note: that the trajectory makes **ClientA** start moving after 2 minutes from the beginning of the simulation. **ClientA** waits at X Pos 0.5 for 1 minute and at X Pos 0.25 for 20 seconds.



#	X Pos (km)	Y Pos (km)	Distance (m)	Altitude	Traverse Time	Ground Speed	Wait Time	Accum Time
1	0.0	0.0	n/a	0.0	n/a	n/a	0h2m0.00s	0h2m0.00s
2	-0.75	0.0	750	0.0	0h0m20.97s	80	0h1m0.00s	0h3m20.97s
3	-0.75	0.02	20	0.0	0h0m2.24s	20	0h0m0.00s	0h3m23.21s
4	-1.0	0.02	250	0.0	0h0m6.99s	80	0h0m0.00s	0h3m30.20s
5	-1.0	0.04	20	0.0	0h0m2.24s	20	0h0m30.00s	0h4m2.44s
6	0.0	0.04	1,000	0.0	0h0m27.96s	80	0h0m0.00s	0h4m30.40s

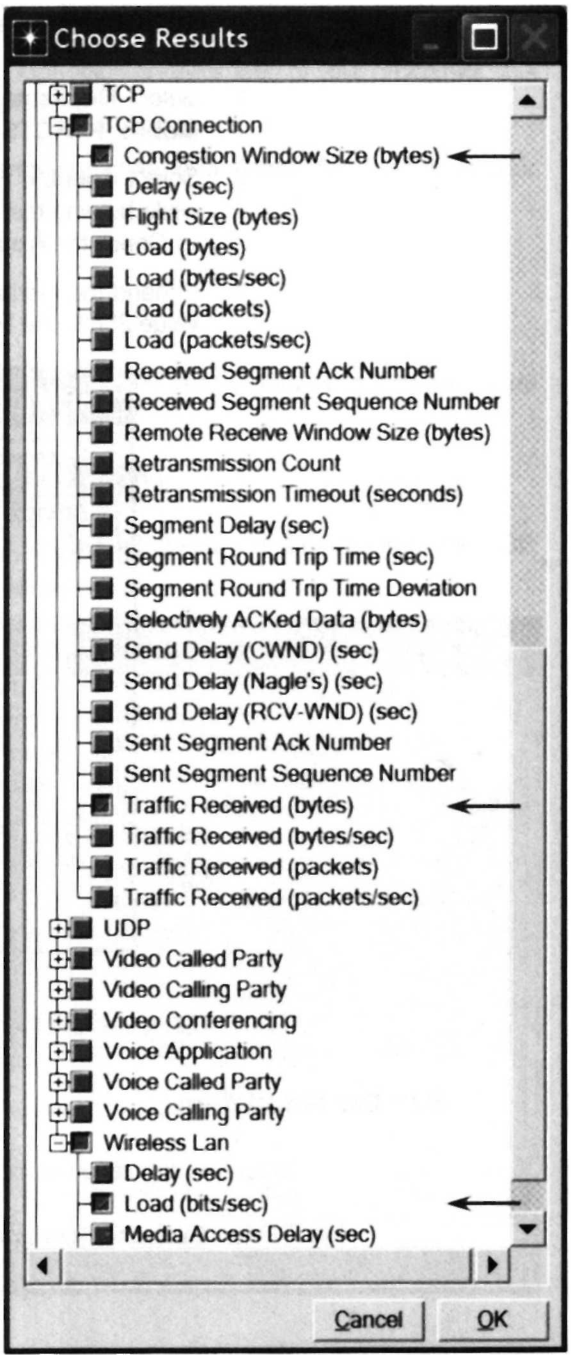
8. Click **OK** and then save your project.

The **trajectory** attribute specifies the name of an ASCII trajectory file that specifies the time and locations that a mobile node will pass through as the simulation progresses.

15.4.3. Configure the Simulation

Here we will configure the simulation parameters:

1. Click on  and the *Configure Simulation* window should appear.
2. Assign **10.0 minutes** to the **Duration** attribute.
3. Assign **256** to the **Seed** attribute.
4. Click **OK** and then save your project.

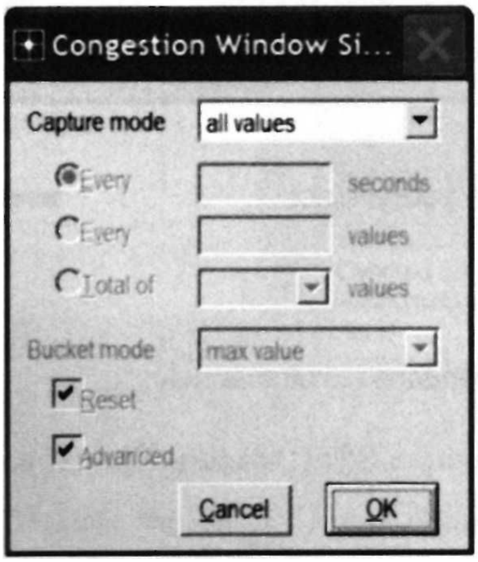


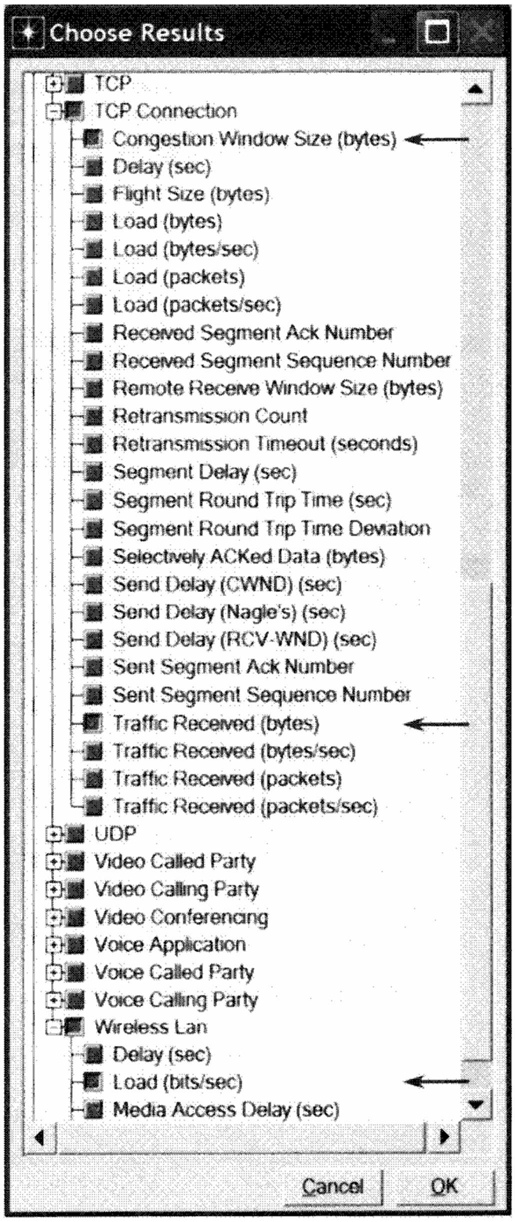
The **Seed** attribute is an integer that is used by the simulation's random number generator. Its default value is 128.

15.4.4. Choose the Statistics

To test the performance of our mobile wireless network 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 Node Statistics hierarchy ⇒ choose the shown three statistics.
3. Right-click on the **Congestion Window Size (bytes)** statistic ⇒ Choose **Change Collection Mode** ⇒ In the dialog box check **Advanced** ⇒ From the drop-down menu, assign **all values** to **Capture mode** as shown ⇒ Click **OK**.



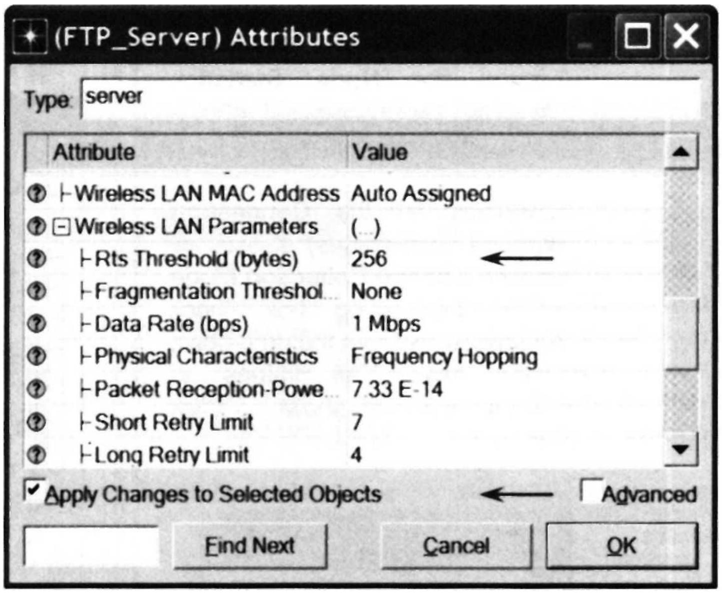


4. Right-click on the **Traffic Received** (bytes) statistic. ⇒ Choose **Change Collection Mode**. ⇒ In the dialog box check **Advanced**. ⇒ From the drop-down menu, assign **all values** to **Capture mode**.
5. Click **OK** twice and then save your project.

15.4.5. Duplicate the Scenario

We will create one more scenarios to utilize the request to send (RTS) and clear to send (CTS) frames to study their effect on minimizing collisions.

1. Select **Duplicate Scenario** from the **Scenarios** menu and give it the name **Mobile_RTSCTS** ⇒ Click **OK**.
2. Select **ClientA**, **FTP_server**, and **ClientB** simultaneously (click on all of them while holding the **Shift** key). ⇒ Right-click on anyone 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 **Rts Threshold (bytes)** attribute.

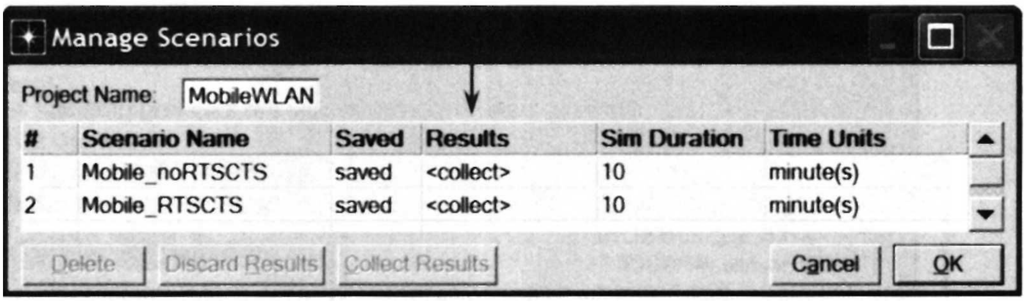


4. Click **OK** and then save your project.

15.4.6. Run the Simulation

To run the simulation for both 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.

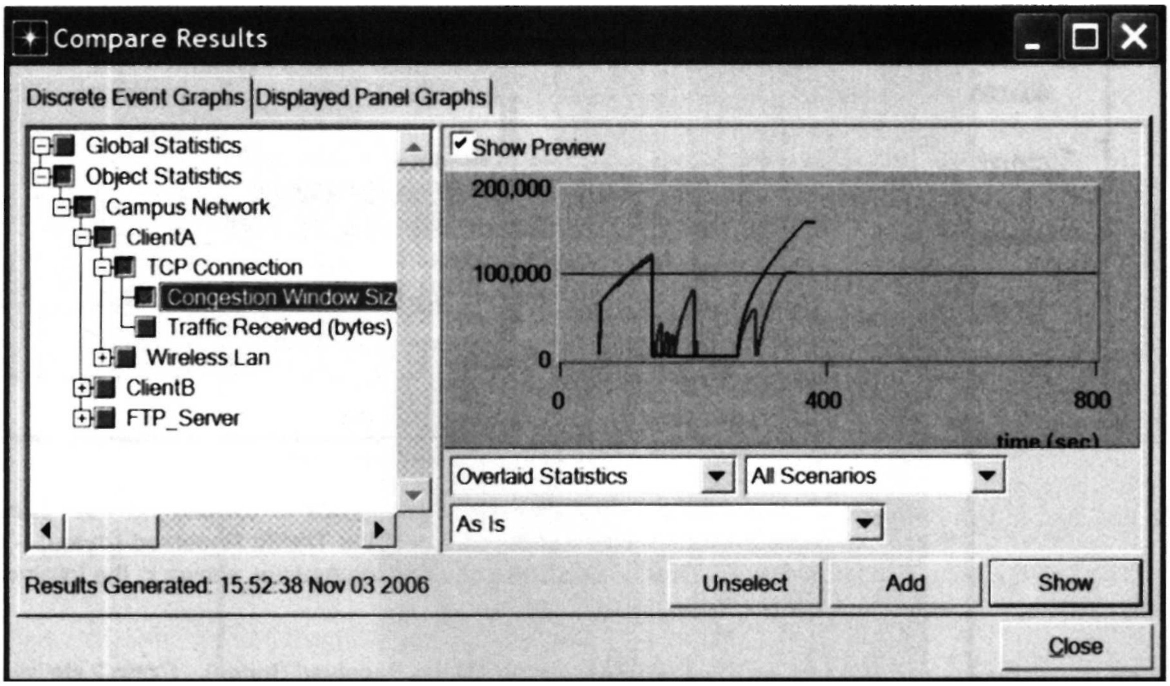


3. Click **OK** to run both simulations. Depending on the speed of your processor, this may take several seconds to complete.
4. After the simulation of both scenarios complete, click **Close** and then save your project.

15.4.7. View the Results

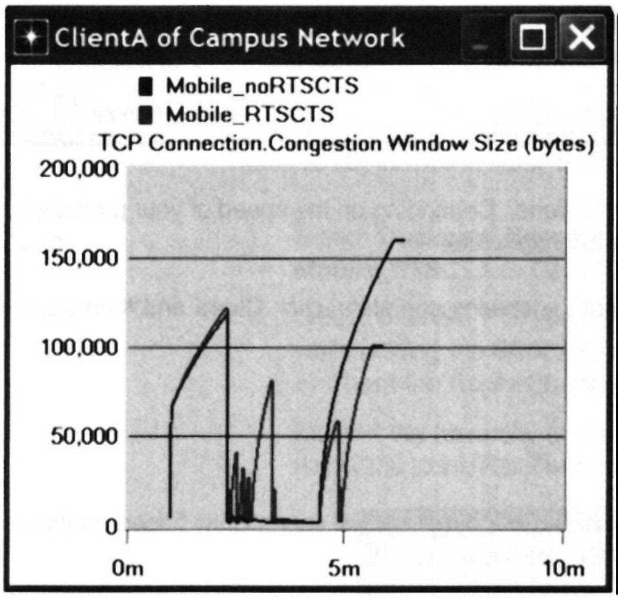
To view and analyze the results (*Note:* Actual results will vary slightly based on the actual node positioning in the project):

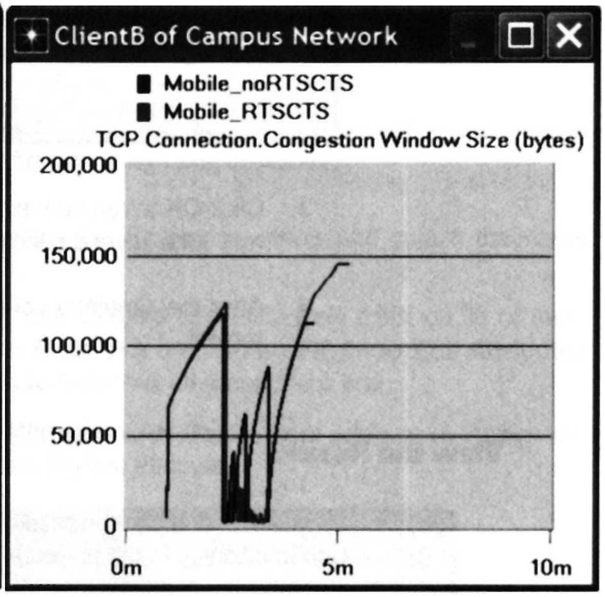
1. Select **Compare Results** from the **Result** menu.
2. Select the **Congestion Window Size (bytes)** statistic for **ClientA** from the **TCP Connection** hierarchy as shown.

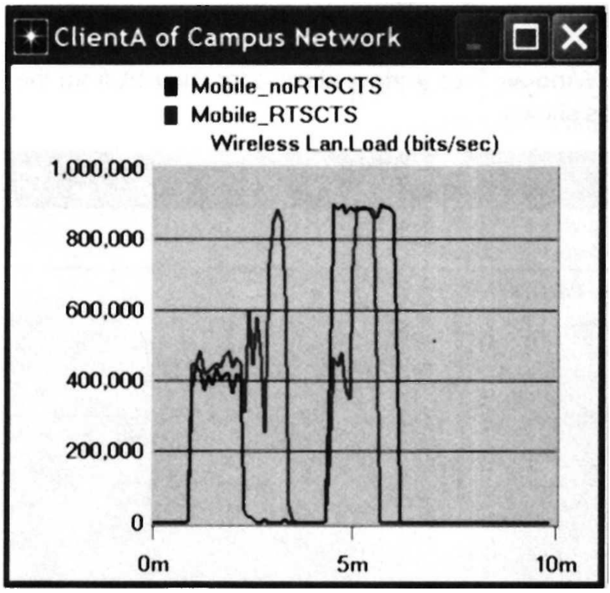


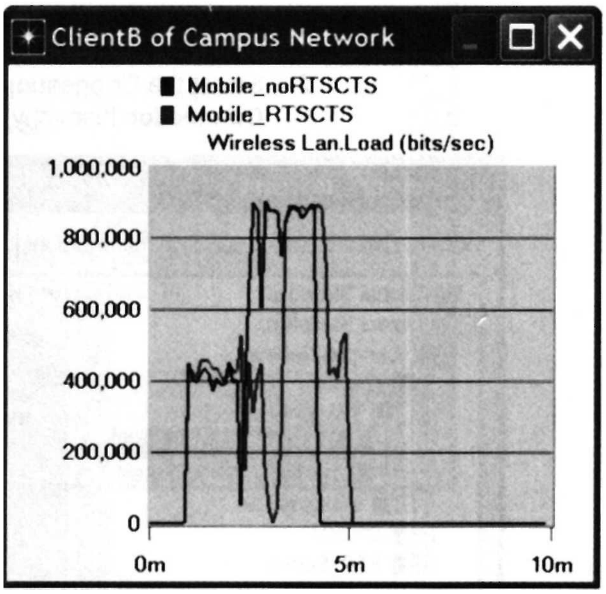
3. Click **Show** to show the result in a new panel.
4. Repeat the above steps for the following statistics:
   a. **Congestion Windows** of **ClientB**;
   b. **Load** for **ClientA** and
   c. **Load** for **ClientB**.

The resulting graphs should resemble the following graphs.

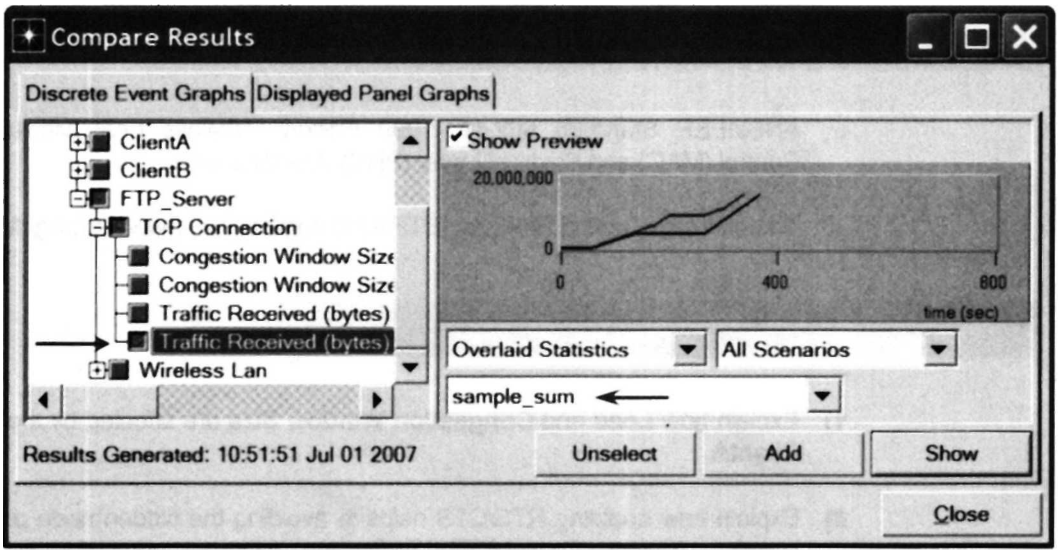


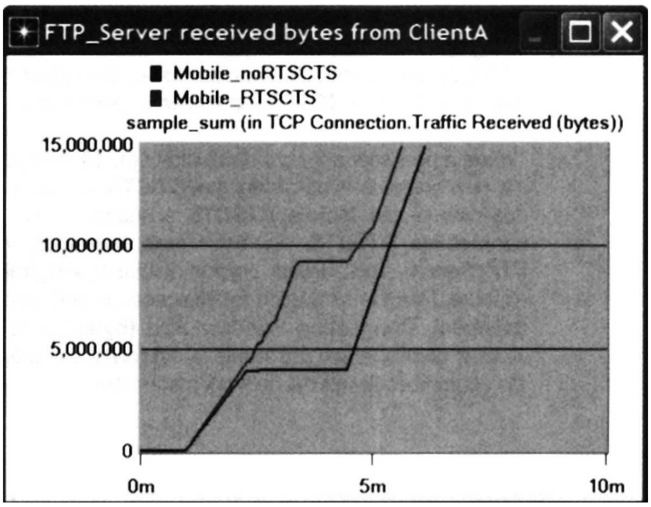


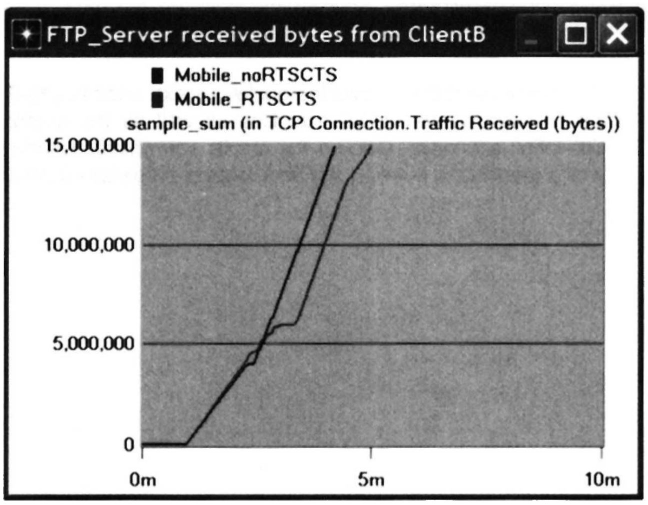




5. Go back to the *Compare Results* dialog box ⇒ Expand the **TCP Connection** hierarchy for the **FTP server** ⇒ Select the **Traffic Received** (bytes) - **Conn 1** statistic ⇒ Select **sample_sum** to replace **As Is** as shown in the following figure ⇒ Click **Show**.
6. Repeat the above step for the **Traffic Received (bytes)-Conn 2** statistic.
7. The resulting graphs should resemble the following graphs.







15.5. *Further readings*

- ANSI/IEEE Standard 802.11, 1999 Edition: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.
- Transmission Control Protocol: IETF RFC number 793 (www.ietf.org/rfc.html).

15.6. *Exercises*

1) Explain how **Load** and **Congestion Window Size** are affected by the mobility of **ClientA**.
2) Explain how enabling RTS/CTS helps in avoiding the hidden node problem and hence explain the effect of RTS/CTS frames on the network performance.
3) The graphs show that the server terminates the FTP session with **ClientA** earlier if RTS/CTS is enabled. On the other hand, the server terminates the FTP session with **ClientB** later if RTS/CTS is enabled. Explain why.
4) Create a new scenario as a duplicate of the **Mobile_noRTSCTS** scenario. Name the new scenario **twoMobiles_noRTSCTS**. Create a second new scenario as a duplicate of the **Mobile_RTSCTS** scenario. Name the second new scenario **twoMobiles_RTSCTS**. In both new scenarios, edit the attribute of the **FTP_Server** and assign **<your initials>_left_trajectory** to its **trajectory** attribute. Run the simulation for all scenarios and create the graphs for the **Load (bits/sec)**, **Congestion Window Size (bytes)**, and **Traffic Received (bytes)** statistic results as we did in this lab. Analyze the graphs explaining the effect of the server mobility on the network performance.

15.7. *Lab Report*

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

NETWORK SIMULATION EXPERIMENTS MANUAL

Prepared by Professor Emad Aboelela, University of Massachusetts/Dartmouth

Networking technologies and concepts are often difficult to explain, even through careful description and well thought out examples. One method for making this information "stick" is to create an environment where networking professionals and students can visualize how networks work by utilizing a software tool that simulates the functions within a network. The tool itself is highly useful in that it provides a virtual environment for an assortment of desirable features such as modeling a network based on specified criteria and predicting its performance.

The *Network Simulation Experiments Manual takes* this instructional tool a step further and provides detailed experiments on core networking topologies for use in this simulation environment. Various scenarios are presented within each topology: Review questions, a lab report, and exercises accompany each assignment as well. The manual also comes with directions for downloading the free and easy-to-install **OPNET IT Guru Academic Edition** software. This software provides a virtual environment for modeling, analyzing, and predicting the performance of IT infrastructures, including applications, servers, and networking technologies.

Prepared by Professor Emad Aboelela of the University of Massachusetts Dartmouth, the experiments in the manual are closely tied to the organization of *Computer Network: A Systems Approach, 4e,* and when used together, serve as a complete tool for understanding how and why computer networks function as they do.

KEY FEATURES

- Written by an instructor who has used OPNET simulation tools in his classroom for numerous demonstrations and real-world scenarios.
- Software download based on an award-winning product made by OPNET Technologies, Inc., whose software is used by thousands of commercial and government organizations worldwide, and by over 500 universities.
- Useful experimentation for professionals in the workplace who are interested in learning and demonstrating the capability of evaluating different commercial networking products, i.e., Cisco routers.
- Covers the core networking topologies and includes assignments on the ethernet, token rings, ATM, Switched LANs, Network Design, RIP, TCP, Queuing Disciplines, QoS, wireless, etc.

About the Author

Dr. Emad Aboelela received his Ph.D. in Computer Engineering from the University of Miami (Florida); M.Sc. and B.Sc. in Computer Science from Alexandria University (Egypt). Before joining the University of Massachusetts Dartmouth he taught at Southern Connecticut State University for two years, and prior to that worked at the University of Miami as a part-time professor and research assistant for five years during which time he received many awards including the Award of Academic Merit.