### Overview

The shape of the traffic that is offered to a network can have a large effect on the resulting delay and variation in delay that the traffic experiences. Smooth, regular traffic patterns are generally easier for routers to handle than bursty, irregular patterns. When a large burst of traffic arrives, a router may not have sufficient capacity to immediately forward the packets, and it must place the packets in a queue. The packets will wait there until capacity is available. In the meantime, the packets experience increased delay. If the size of the queue varies over time (due again to irregular traffic patterns), incoming packets will experience different amounts of queuing delay. In general, for any application, it is desirable to reduce delay. Applications based on voice and video, however, cannot tolerate a large amount of delay variation either.

Traffic-shaping schemes, such as leaky bucket or token bucket, are designed to smooth out the traffic patterns at the source. The hope is that smoother patterns will see less delay and less variation in delay.

#### Objective

To examine the effects of traffic shaping on router performance. We will examine buffer usage, queuing delay, and queuing delay variation when generating constant bit rate (CBR) traffic, and two varieties of bursty traffic.

### **Build the Simulation Model**

Start up OPNET IT Guru Academic Edition.
Select the File tab => New...
Choose Project and click on OK.
Change the Project Name to xx\_QoS\_Shaping (where xx are your initials). Set the Scenario Name to CBR and click on OK.
In the Initial Topology window, select Create Empty Scenario and click on Next.
In the Choose Network Scale window, select Office and click on Next.
In the Specify Size window, click on Next.
In the Select Technologies window, click on Next.
In the Review window, click on OK.

📩 Startup Wizard: Review		$\mathbf{X}$
Review the values you have chosen. Use the 'Back' button to make changes.	Scale Size Model Family None Selected	Office 100 m x 100 m
	Quit	<u>Back</u>

First, we will modify the existing **File Print (Heavy)** application to generate traffic at a constant bit rate. The File Print application is based on a simple model and is easy to modify.

Select an **Application Config** object from the Object Palette and place it in the project workspace. Right click on the object and choose **Edit Attributes**. Set the **name** attribute to **Applications**.

Edit the **Application Definitions** attribute and set the value to **Default**. Now expand the **Application Definitions** item, the **row 6** item (which corresponds to the **File Print (Heavy)** application) and the **Description** item. Edit the **Print** attribute. Set the **Print Interarrival Time (seconds)** attribute to **constant(0.0055)**. Set the **File Size (bytes)** attribute to **constant(1000)**. The application you have now defined will transfer one 1000 byte file every 0.0055 second (5.5 milliseconds) without variation. Click on **OK** to close the window.

🛨 (Print) Table	- 🗆 🗙
Attribute	Value
Print Interarrival Time (seconds)	constant (0.0055)
File Size (bytes)	constant (1000)
Symbolic Printer Name	Printer
Type of Service	Best Effort (0)
	<b>*</b>
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🗶 (node_0) Attributes	
Type: Utilities	
Attribute	Value
⑦ ⊢ name	Applications
⑦ - model	Application Config
ACE Tier Information	None
② — Application Definitions	()
Prows	16
+ row 0	Database Access (Heavy),()
+ row 1	Database Access (Light),()
+ row 2	Email (Heavy),()
+ row 3	Email (Light).()
+ row 4	File Transfer (Heavy),()
+ row 5	File Transfer (Light),()
- row 6	
⑦ - Name	File Print (Heavy)
⑦	()
⑦	Off
⑦	Off
⑦ – Email	Off
⑦ ⊢Ftp	Off
P Http	Off
Print	[]
A Domoto Login	In#
Apply Changes to Selected Objects	☐ A <u>d</u> vanced
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Select a **Profile Config** object from the Object Palette and place it in the project workspace. Right click on the object and choose **Edit Attributes**. Set the **name** attribute to **Profiles**.

Expand the **Profile Configuration** attribute and set the **rows** attribute to **1**. Expand the **row 0** attribute and set the **Profile Name** to **Data Stream**. Expand the **Applications** attribute and set the **rows** attribute to **1**. Expand the **row 0** attribute and set the **Name** to **File Print (Heavy)**. Click on **OK** to close the window.

🛨 (Profiles) Attributes	
Type: Utilities	
Attribute	Value
⑦ ⊢ name	Profiles
⑦ - model	Profile Config
Profile Configuration	[]
? Froms	1
row 0	
Profile Name	Data Stream
Applications	[]
	1
(?) – Name	File Print (Heavy)
Optimized Control (Seconds)	uniform (5,10)
Puration (seconds)	End of Profile
Operation Mode	Serial (Urdered)
CO     FStart Time (seconds)	uniform (100,110)
FDuration (seconds)	End of Simulation
	Unce at Start Time
	-
Apply Changes to Selected Objects	☐ A <u>d</u> vanced
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Select a **QoS Attribute Config** object from the Object Palette and place it in the project workspace. Right click on the object, choose **Set Name**, and set the **Name** to QoS. Click on **OK** to close the window. The QoS object is necessary as we will be configuring a router to do quality of service monitoring.

Now we will build a client-server system based on the file printing application and profile that we just created.

Click on **Configure Palette** in the Object Palette. Click on **Node Models**. Scroll down and choose to include the **ppp\_server\_adv** and **ppp\_wkstn\_adv** models. Click on **OK** twice, and choose to save your model to finish configuring the palette.

🗄 Select Included Entries			0
Entries		Status	
ppp_printer_adv		not included	
ppp_rpg_wkstn		not included	
ppp_rpg_wkstn_adv		not included	
ppp_server_adv		included	
ppp_unix_server		not included	
ppp_unix_wkstn		not included	
ppp_wkstn_adv		included	
priority_switch		not included	
profile_config_60		not included	•
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Select a **ppp\_wkstn\_adv** device from the Object Palette and place it in the project workspace. Right click on the workstation and choose **Edit Attributes**. Modify the **name** attribute of the device to **Client**. Edit the **Application: Supported Profiles** attribute. Set the **rows** attribute to **1**, expand the **row 0** attribute, and set the **Profile Name** to **Data Stream**. Expand the **Application: Transport Protocol Specification** attribute, and set the **Print Transport** attribute to **UDP**. Click on **OK** to close the window. By specifying that UDP be used rather than TCP, we eliminate the TCP connection setup and teardown overhead that would affect our results.

🛨 (node_0) Attributes	
Type: workstation	
Attribute	Value
⑦ ⊢ name	Client
	DDD wkstn adv
⑦ ∓ Application: ACE Tier Configuration	Unspecified
Application: Destination Preferences	None
The Application: Multicasting Specification     Application     Applic	None
(?) + Application: RSVP Parameters	None
Application: Segment Size	64,000
① + Application: Source Preferences	None
Papelication: Supported Profiles	()
Prows	1
now 0	
Profile Name	Data Stream
Participation: Supported Services	None
Participation: Transport Protocol Specification	()
Custom Application Transport	TCP + UDP
⑦ – Database Transport	TCP
Period Contract Provide America Contract Pr	TCP
Ptp Transport	TCP
P Http Transport	TCP
Provide Argent Argen	TCP
Print Transport	UDP 🗾
	<b>&gt;</b>
Apply Changes to Selected Objects	☐ A <u>d</u> vanced
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Select a **ppp\_server\_adv** device from the Object Palette and place in the project workspace. Right click on the device and choose **Edit Attributes**. Modify the **name** attribute of the server to **Server**.

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Edit the **Application: Supported Services** attribute. Set the **rows** attribute to **1** and expand the **row 0** attribute. Set the **Name** to **File Print (Heavy)**. Click on **OK** to close the window. Expand the **Application: Transport Protocol Specification** attribute, and set the **Print Transport** attribute to **UDP**. Click on **OK** to close the window.

🗶 (Application: Supported Serv	rices) Table	
Name	Description	A
File Print (Heavy)	Supported	
		<b>v</b>
-		
1 Rows Delete	Insert Dyplicate	Move Up Move Down
D <u>e</u> tails <u>P</u> romote		<u>C</u> ancel O <u>K</u>

품 (node_0) Attributes	
Turner Server	
Type. Joornal	
Attribute	Value 🔺
name	Server
model	ppp_server_adv
	Unspecified
Participation: Destination Preferences	None
⑦	None
① + Application: RSVP Parameters	None
Participation: Segment Size	64,000
①	None
①	None
Participation: Supported Services	[]
Participation: Transport Protocol Specifica	[]
Output Custom Application Transport	TCP + UDP
Oatabase Transport	TCP
Periodic Construction (Construction)	TCP
Plant Provide the second se	TCP
Http Transport	TCP
Remote Login Transport	TCP
Print Transport	UDP
Video Conferencing Transport	UDP
Occe Transport	UDP
Domoto Storago Corrier Transport	
Apply Changes to Selected Objects	☐ A <u>d</u> vanced
Eind Next	<u>C</u> ancel <u>O</u> K

Select an **ethernet4\_slip8\_gtwy** device from the Object Palette and place it in the project workspace. Right click on the router and choose **Set Name**. Set the **Name** to **Router** and click on **OK** to close the window.

Select a **PPP\_DS1** link from the Object Palette and use it to connect the server to the router. Select a **PPP\_DS3** link from the Object Palette and use it to connect the client to the router. The inequality in data rates will help us to see the effects of different traffic-shaping schemes.

Right click on the PPP link which connects the Router and the Server, and choose **Edit Attributes**. Inspect the **port a** and **port b** attributes to see which interface is being used on the Router (IF10 in our example). Your configuration may differ from the one shown depending on how you placed your PPP link. You will need this interface information when viewing results. Click on **OK** to close the window.

🗶 (Router <-> Server) Attributes	
Attribute	Value
⑦ ⊢ name	Router <-> Server
⑦ - model	PPP_DS1
port a	Router.PPP (IF10 P0)
Port b	Server.PPP (IF0 P0)
⑦	None
	~
Apply Changes to Selected Objects	☐ A <u>d</u> vanced
<u>Eind Next</u>	<u>C</u> ancel <u>O</u> K

Left click on the router to select it, and then select the **Protocols** tab  $\Rightarrow$  **IP**  $\Rightarrow$  **QoS**  $\Rightarrow$  **Configure QoS...** Note that the default QoS scheme is FIFO (First-In First-Out). Click on the radio button marked **Interfaces on selected routers**, and click on **OK** to finish configuring quality of service on the router.

迷 QoS Configurati	on <b></b>				
This operation will ov QoS configuration on	erwrite the existing IP interfaces.				
QoS Scheme:	FIFO				
QoS Profile:	FIFO Profile				
Apply the above :	selection to subinterfaces				
Apply the above s	Apply the above selection to:				
C Interfaces ac	C Interfaces across selected link(s)				
Interfaces on selected router(s)					
✓ Visualize QoS Configuration					
<u>(</u>	2ancelK				

Our model is now complete.

Project: Qos     Eile Edit View	_Shaping Scenario: CBR	[Subnet: top.Office	Network] results Windows Help	
0.0 12.5	25.0 37.5	50.0 62.5	75.0 87.5	
12.5				
25.0				
37.5				
50.0	Client	Router	Server	
62.5				
75.0				
87.5	ation Profiles			
		400		•

# **Configure the Simulation**

Select the Simulation tab => Choose Individual Statistics... Expand the Node Statistics item and the IP Interface item, and select the Buffer Usage (bytes), the Queue Delay Variation (sec), the Queuing Delay (sec), and the Traffic Dropped (bits/sec) statistics. Click on OK to close window.



Select Simulation => Configure Discrete Event Simulation... Under the Common tab, set the Duration to 250, and the unit to second(s). Click on OK to close the window.

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迷 Configure Simu	ılation: Qos_Sha	ping-CBR			
Common Global Attrit	butes Object Attribut	es Reports S	LAs Animation Profiling Advance	ed Environment	Files
Duration:	250	second(s)	<b>_</b>		
Seed:	128				
Values per statistic:	100				
Update interval:	100000	Events			
Enable simulation	log				
	-				
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# **Duplicate the Scenario**

We are now going to duplicate the scenario and change the characteristics of the data stream. We will create one scenario where the stream interarrivals are based on a uniform distribution, which provides somewhat variable interarrival times, and another based on the exponential distribution, which provides extremely variable interarrival times. In all three cases, however, the average amount of traffic generated per second will be the same. This will allow us to compare the effects on the router of traffic which is shaped differently.

Choose Scenarios => Duplicate Scenario, and name the new scenario Uniform. Click on OK to create the scenario.

Right click on the Applications node and choose **Edit Attributes**. Expand the **Application Definitions**, row 6 (which corresponds to **File Print (Heavy)**), and **Description** attributes. Edit the **Print Interarrival Time** (seconds) attribute and set the value to **uniform(0.0005,0.0105)**. Click on **OK** twice to close the windows. Packets will now be generated at random intervals ranging from 0.5 to 10.5 milliseconds.

🛨 (Print) Table	
Attribute	Value
Print Interarrival Time (seconds)	uniform (0.0005, 0.0105)
File Size (bytes)	constant (1000)
Symbolic Printer Name	Printer
Type of Service	Best Effort (0)
	<b>_</b>
<u>D</u> etails <u>P</u> romote	<u>C</u> ancel <u>O</u> K

Choose Scenarios => Duplicate Scenario, and name the new scenario Exponential. Click on OK to create the scenario.

Right click on the Applications node and choose to Edit Attributes. Expand the Application Definitions, row 6 (corresponding to File Print (Heavy)), and Description attributes. Edit the Print Interarrival Time (seconds) attribute and set the value to exp(0.00055). Click on OK twice to close the windows. Packets will now be generated at random intervals with a mean of 5.5 milliseconds.

H	f (Print) Table	
	Attribute	Value
	Print Interarrival Time (seconds)	exponential (0.0055)
	File Size (bytes)	constant (1000)
	Symbolic Printer Name	Printer
	Type of Service	Best Effort (0)
		v
	<u>D</u> etails <u>P</u> romote	<u>Cancel</u>

### **Run the Simulation**

Select the Scenarios tab => Manage Scenarios...

Edit the **Results** field in all three rows and set the value to **<collect>** or **<recollect>**.

Click on **OK** to run the scenarios (one after the other).

When the simulation has completed, click on **Close** to close the window.

\star M Proje	anage Scenarios act Name: Qos_Shaping				- 6	
#	Scenario Name	Saved	Results	Sim Duration	Time Units	
1	CBR	unsaved	<collect></collect>	250	second(s)	-
2	Uniform	unsaved	<collect></collect>	250	second(s)	
3	Exponential	unsaved	<collect></collect>	250	second(s)	
						Ţ
	Delete Discard Results Collect Results			Cancel	<u>0</u> K	

#### **Inspect and Analyze Results**

Select the **Results** tab => **Compare Results...** 

Select and expand the **Object Statistics** item, the **Office Network** item, the **Router** item, and the **IP Interface** item. Select the **FIFO Buffer Usage (bytes) IF10 Q0** statistic. Note that interface 10 (IF10) is the interface

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on the Router that connects it to the Server. If, during configuration setup, you found that a different interface was used in your model, replace IF10 with that interface for the rest of the results analysis steps. Use the **As Is** mode to view all statistics. Click on **Show** to see a detailed version of the graph. This statistic shows how full the router's buffers were during the simulation. The buffers can fill up if a large burst of traffic is received at once. You can see that the router can handle the traffic easily if the packets are received at constant intervals. The buffer does not fill at all. When packets are received more irregularly, in the uniform distribution case, buffer usage begins to grow. When packets are received very irregularly, buffer usage is high. Click on the close window icon and choose to **Delete** the panel. Click on the statistic again to disable the preview.



Select the **FIFO Queuing Delay (sec) IF10 Q0** statistic. Click on **Show** to see a detailed version of the graph. This statistic shows how long packets had to wait in the queue before being sent. As a router's buffers fill up, incoming packets must wait longer to be sent. Since the buffers were always empty in the CBR case, there is no queuing delay. The uniform case and exponential case see longer delays due to the high buffer usage in those cases. Click on the close window icon and choose to **Delete** the panel. Click on the statistic again to disable the preview.



Select the **FIFO Queue Delay Variation (sec) IF10 Q0** statistic. Click on **Show** to see a detailed version of the graph. This statistic shows the variation in how long packets had to wait in the queue before being sent. When the size of the router's queue changes over time, the delay that each incoming packet sees will be different. The buffers were always empty in the CBR case, so the variation in queuing delay is zero. The uniform case and exponential case had buffers that filled and emptied often, causing a significant in variation delay. Click on the close window icon and choose to **Delete** the panel. Click on the statistic again to disable the preview.



You may also inspect the **FIFO Traffic Dropped (bits/sec) IF10 Q0** statistic to see that no packets were dropped due to full buffers in any of the three scenarios.

Save your model and close all windows.

### Questions

1. Look up the formula for the mean of the three distributions used in this lab (constant, uniform, exponential). Find the mean for each. Using the average packet interarrival time and packet size, calculate the load which the client is generating (in bits per second).

2. Choose to collect **Node Statistics**, **Client Print**, **Traffic Sent** (**bytes/sec**) and rerun the three scenarios. Did the measured traffic sent match up with the numbers you calculated in Question 1? Why or why not?

3. Look up the formula for the variance of the three distributions used in this lab (constant, uniform, exponential). Find the variance of each. How does the variance of the packet interarrival time affect the buffer usage, queuing delay, and queuing delay variation?

4. Duplicate each scenario, and copy and paste the client to create two clients. Connect the new client to the router. Edit the **File Print (Heavy)** application and double the interarrival times. By doing this, each client will generate half the amount of traffic as shown in the lab exercise, but since there are two clients, the same total amount of traffic will be generated. Rerun the three scenarios, and compare the results (buffer usage, queuing delay, and queuing delay variation) with your original results. Were the results different? If so, why?

5. Duplicate the Uniform scenario, and modify the interarrival time of the **File Print (Heavy)** application. In the lab exercise, the uniform interval is 10 milliseconds wide. Make the interval 20 milliseconds wide and rerun the simulation. Make sure that the mean of the interval is still the same. How does the wider interval affect the results? Repeat for intervals which are 40, 80, 160, and 320 milliseconds wide. Graph your results for the five intervals and explain the behavior you see.