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The NIST ATM Network Simulator

Operation and Programming

Version 1.0

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TABLE OF CONTENTS

Introduction 1
Purpose 1
Terminology in this Manual 2

PART 1. User's Manual 3
1.1 Objectives and Overview 3
1.2 Component Descriptions 5
1.2.1 ATM Switch. 5
1.2.2 Broadband Terminal Equipment (B-TE). 5
1.2.3 ATM Application. 5
1.2.4 Physical Link. 5
1.3 Executing the Program 6
1.4 The Display 7
1.4.1 The Network Window 7
1.4.2 The Text Window 7
1.4.3 The Control Panel 7
1.4.3.1 Analog Clock. 8
1.4.3.2 Digital Clock. 8
1.4.3.3 Control Buttons. 9
1.5 Operating the Simulator 11
1.5.1 Loading a Network Configuration 11
1.5.2 Creating a Network Configuration 11
1.5.2.1 Creating Components. 11
1.5.2.3 Linking Components. 12
1.5.2.3 Creating Routes. 12
1.6 Operational Features 13
1.6.1 Displaying Information about the Network 13
1.6.1.1 Component Information Windows. 13
1.6.1.2 Meters. 14
1.6.1.3 Logging Data. 15
1.6.1.4 Log File Format. 15
1.6.2 Making Modifications 16
1.6.2.1 Modifying Components. 16
1.6.2.2 Deleting Components. 16
1.6.3 Manipulating the Network Display 16
1.6.3.1 Raising/Lowering Windows. 16
1.6.3.2 Moving Windows. 16
1.6.3.3 Resizing Windows. 17
1.6.3.4 Resizing Information Windows. 17
1.6.4 Saving a Network Configuration 17

1.6.5 Post Simulation Analysis using the Log File 17
1.7 Simulator Concepts 19
1.7.1 Simulation Clock 19
1.7.2 ATM Switch 19
1.7.3 Broadband Terminal Equipment (B-TE) 19
1.7.4 ATM Applications 20
1.7.5 Link Components 20

PART 2. Programmer's Guide 21
2.1 Objectives and Overview 21
2.2 Components 22
2.2.1 Classes and Types 22
2.2.2 Component Data Structures 23
2.2.3 Parameters 23
2.2.4 Neighbors 27
2.2.5 Relationship of Data Structures 28
2.2.6 Action Routines 29
2.3 Events 31
2.3.1 Command Set (EV_CLASS_CMD) 31
2.3.2 Regular Events (EV_CLASS_EVENT) 32
2.3.3 Private Events 33
2.3.4 The Event Manager 33
2.4 ATM Network-Related Issues 35
2.4.1 ATM Cell Definition 35
2.4.2 Setting Up the ATM Virtual Channel 36
2.5 Tools 37
2.5.1 Lists and Queues 37
2.5.2 Other Tools 39
2.5.3 Debugging 39
2.6 Creating New Versions 41

APPENDIX A: Parameter Information 43
A.1 ATM Switches 43
A.2 Broadband Terminal Equipment (B-TE) 45
A.3 ATM Applications 46
Constant Bit Rate (CBR) Information Window 47
Variable Bit Rate (VBR) (Poisson) Information Window 47
Variable Bit Rate (VBR) (Batch) Information Window 47
Available Bit Rate (ABR) (Constant) Information Window 48
Available Bit Rate (ABR) (Poisson) Information Window 48
Available Bit Rate (ABR) (Batch) Information Window 48
TCP/IP Information Window 49
A.4 Link Components 51

APPENDIX B: Meter Types 53

APPENDIX C: Configuration File Formats 55
C.1 Format of the SAVE file. 55
C.2 Format of the SNAP File. 56

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ABSTRACT

An Asynchronous Transfer Mode (ATM) network simulator has been developed to provide a means for researchers and network planners to analyze the behavior of ATM networks without the expense of building a real network. The simulator is a tool that gives the user an interactive modeling environment with a graphical user interface. With this tool the user may create different network topologies, control component parameters, measure network activity, and log data from simulation runs. Part 1 of this document is the user's manual for the simulator; it includes instructions for creating network configurations, specifying component parameters, manipulating the display, logging and saving measurements, and post-processing of data. Part 2 has been prepared as a guide for the user who wishes to modify the simulator software to accommodate network components not previously defined or to change the behavior of components already defined.

Introduction

The ATM Network Simulator was developed at the National Institute of Standards and Technology (NIST) to provide a flexible testbed for studying and evaluating the performance of ATM networks. The simulator is a tool that gives the user an interactive modeling environment with a graphical user interface. NIST has developed this tool using both C language and the X Window System running on a UNIX platform. This tool is based on a network simulator developed at MIT[1] that provides support for discrete event simulation techniques and has graphic user interface (GUI) representation capabilities.

The ATM Network Simulator allows the user to create different network topologies, set the parameters of component operation, and save/load the different simulated configurations. While the simulation is running, various instantaneous performance measures can be displayed in graphical/text form on the screen or saved to files for subsequent analysis.

Purpose

The ATM network simulator is a tool to analyze the behavior of ATM networks without the expense of building a real network. There are two major uses for the simulator: as a tool for

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[1] A. Heybey, "The Network Simulator," *Laboratory of Computer Science*, Massachusetts Institute of Technology, October 1989.

ATM network planning and as a tool for ATM protocol performance analysis. As a planning tool, a network planner can run the simulator with various network configurations and traffic loads to obtain statistics such as utilization of network links and throughput rates of virtual circuits. It could be used to answer questions such as: where will be the bottlenecks in the planned network, what is the effect of changing the speed of a link, will adding a new application cause congestion, etc. Statistics are reported directly to the screen or logged in a data file for further processing.

As a protocol analysis tool, a researcher or protocol designer could study the total system effect of a particular protocol. For example, one could investigate the effectiveness of various flow control mechanisms for ATM networks and address such issues as: mechanisms for fair bandwidth allocation, protocol overhead, bandwidth utilization, etc. In order to conduct experiments, an investigator must first change or add additional codes to implement the protocol to be studied. The simulator is designed in such a way that modules simulating components of an ATM network can be easily changed, added, or deleted. Activities can be recorded on a cell by cell basis for subsequent analysis.

Terminology in this Manual

The network to be simulated consists of several *components* sending messages to one another. The components available include *ATM Switches*, *Broadband Terminal Equipment (B-TE)*, and *ATM Applications*. Switches and B-TE components are interconnected with *Physical Links*; a Physical Link is also considered a component. The ATM Applications are logical entities that run on B-TE (hosts). The Applications may be considered as traffic generators that are capable of emulating variable or constant bit rate traffic sources. ATM Applications are connected to each other over a *route* that uses a selected list of adjacent components to form an end-to-end virtual connection.

All components are characterized by one or more *parameters*. Parameters fall into two categories, input and output; both kinds are listed in *information windows* which appear next to the applicable component when the user so desires. All input parameters may be specified by the user at the time of component creation or they may be modified later. Network activity may be observed by opening *meter windows* to display selected parameters. There are various types of meter windows available and they can be placed anywhere on the screen. Parameter information may also be *logged*, i.e., stored on disk in a file named *sim_log.xxxx* where *xxxx* is the process ID of the simulator.

PART 1. User's Manual

1.1 Objectives and Overview

This part of the document provides information for the simulator user to create network topologies using simulated ATM switches, terminal equipment, and physical links. The manual includes instructions for display manipulation, component linking and routing, parameter setting, data logging, and post-simulation analyses.

The user may select from a variety of applications, the behavior of which will determine the kind of traffic generated for transmission through the network. The user may control the parameters associated with these components, define the routes, and specify many details concerning the logging and display of performance data. The primary user interface to the simulator is through an X Windows display screen. The screen simultaneously displays the network configuration, a control panel for running the simulation, and parameter information. The display contains a text window for user prompts which also provides a place for parameter data entry. Output parameter values may be be displayed in numerical form in "information windows" or as graphical "meters." Output parameter values may also be tagged for logging to a file; the data logging frequency is determined by the user.

1.2 Component Descriptions

The following are brief, general descriptions of the major building blocks of the simulated ATM Network. For more detailed functional descriptions, see **1.7 Simulator Concepts** and **2.2 Components**. A complete list of input and output parameters available for each component can be found in **Appendix A**.

1.2.1 ATM Switch. This is the component used to switch or route cells over several virtual channel links. When a switch accepts an incoming cell from a Physical Link it looks in its routing table to determine which outgoing link should send it. If the outgoing link is busy, the switch will queue the cells destined for that link and not send them until free cell slots are available for transmission. The user may specify the processing delay time, maximum output queue size, and queue size thresholds. The parameters that can be monitored for a switch include the number of cells received, number of cells in an output queue, number of cells dropped, and the status of congestion flags.

1.2.2 Broadband Terminal Equipment (B-TE). This is a component to simulate a broadband ISDN node, e.g., host computer, workstation, etc. A B-TE component has one or more ATM Applications on one side and a physical link on the other side. Cells received from the Application side are forwarded to the physical link; if the link is busy the cells go into a queue. The user can specify the maximum output queue size. The parameters that can be monitored are the number of cells in an output queue and the number of cells dropped.

1.2.3 ATM Application. This is a component to emulate the behavior of an ATM application at the end-point of a link. It can be considered as a traffic generator, either with a constant or variable bit rate. The user specifies the bit rate for constant bit rate (CBR) applications. For variable bit rate (VBR) applications the user sets the burst length, interval between bursts, and the mean rate. For lower priority traffic, the user may create an available bit rate (ABR) application. For all of the application types, the user sets the start time and the number of megabytes to be sent. Other application types that can be simulated include TCP/IP applications.

1.2.4 Physical Link. This component simulates the physical medium (copper wire or optical fiber) on which cells are transmitted. The user may choose the link speed from a list of several different standard rates. The user also specifies the length of the link. The output parameter reported by the simulator is link utilization in terms of bit rate (Mbits/s).

1.3 Executing the Program

To execute the ATM Network Simulator, the following is typed at the command line :

sim [-x] [-s seed] [*configfile* [stoptime]]

where:

-x Used for running the simulator in background mode. With this option the simulator will not use X Windows; it will run on a machine that does not have X Windows. When using this option a *configfile* must be specified, otherwise the simulator will have no network to simulate and will produce no meaningful results. Also, the *configfile* specified should be a "snapshot" that has some parameters logged to disk so that the simulator run produces some results.

-s Allows the user to specify the seed for the random number generator. If this option is omitted the current time (in UNIX format) is used as the seed. The seed actually used is printed at the beginning of each simulator run, and is saved as a comment in any log files produced by the simulator. Specifying a particular seed is useful if identical results are expected from successive simulator runs.

configfile A file describing the configuration of the network to simulate. Such a file is produced by the SAVE and SNAP commands in the simulator.

stoptime Length of time (in microseconds of simulated time) for the simulator to run. Most useful when running non-interactively (with the-x option). When the simulator stops, it will automatically produce a "snap" file of its current state.

1.4 The Display

The display is composed of three major parts:

- A network window to display ATM network configurations. This window is used both while creating the configurations and to show network activity while the simulation is running.

- A text window for messages that will prompt the user, and to provide a place for the user to input text or parameter values.

- A control panel that consists of a clock and several control buttons, such as START, QUIT, etc..

1.4.1 The Network Window

Figure 1 is an example of the simulator screen seen by the user once a network configuration has been created. The entire area not otherwise occupied by clock and control buttons is the Network Window. If the program is started with no *configfile* this area is blank. The network is represented as a collection of components connected to each other in the desired configurations. ATM switches and broadband terminals (B-TEs) are represented by rectangular boxes while ATM Applications are represented by ellipses; both shapes contain the name of the component. ATM switches and B-TEs are interconnected by Physical Links. The Links are also considered components and are identified by name, but they are represented on the figure by straight lines. The connection between a B-TE and an ATM Application is also represented by a line but is not considered a component, i.e., it is not a physical entity and has no associated parameters.

Other information (not shown on the figure) is displayed in the Network Window as required. When creating or modifying a component an information window appears beside its symbol, displaying the component's parameters. When a virtual connection is established between ATM applications a dotted line appears denoting the path of the information flow. When a simulation is running, one or more meters may appear on the screen to display information about selected parameters.

1.4.2 The Text Window

The text window appears as a bar at the bottom of the screen. The text window allows the program to present various messages to the user. In addition, any keyboard input is displayed in the text window. The cursor does not need to be in the text window when entering information with the keyboard. When entering information using the keyboard, pressing "Return" without entering any text will tell the program to accept a default value or to abort that operation.

1.4.3 The Control Panel

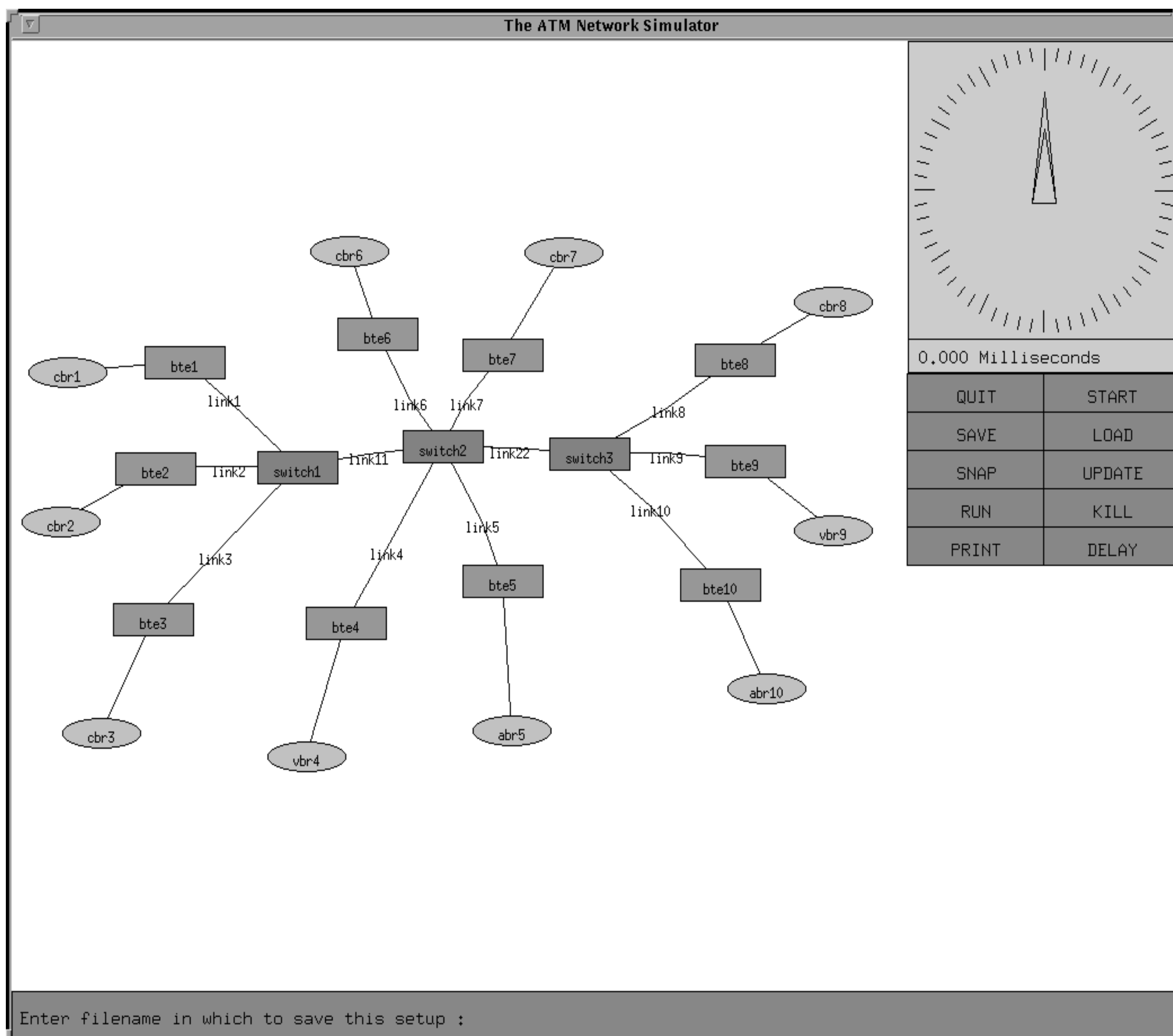


Figure 1. Typical Simulator Screen

The control panel appears on the right hand portion of the screen. It contains an analog clock, a digital clock, and an array of control buttons.

1.4.3.1 Analog Clock. The analog clock indicates the passage of simulator time in a graphic style. The intent is not a precise timer but to give the user an indication of how busy the simulator is. A tick is a movement of 6 degrees around the circle. Each tick of the big hand represents 1 millisecond. Each tick of the small hand represents one revolution of the big hand (60 milliseconds).

1.4.3.2 Digital Clock. The digital clock provides a display of current simulator time accurate to the nearest 10 nanoseconds.

1.4.3.3 Control Buttons. The following is a description of the function of each control button. All of the functions are initiated by clicking with the **middle** mouse button.

START	Clicking on this button will start the simulation with simulated time initialized to zero. The simulation can be restarted as many times as the user wishes; each click on the button will initialize the simulation.
PAUSE/RUN	This button toggles between two modes. When the simulation is running the word PAUSE will be displayed. Clicking on the button will then stop all activity with all parameter and time information held in place. With the simulation stopped, the button label will change to RUN; clicking on it will cause the simulation to resume running with current settings.
DELAY	This button allows the user to slow down the simulation by setting a delay between each event firing. The text window will appear asking for the desired delay (in microseconds).
UPDATE	Clicking on this button will toggle screen updating on or off. The simulation will run faster with screen updating turned off. The clock will continue to be displayed with updating turned off. Clicking on a component while updating is off will cause the parameter window for that component to appear with current data. Clicking on the component a second time will make the window disappear.
KILL	This button may be used to stop a simulation in progress or to eliminate components. Clicking on the KILL button while a simulation is in progress stops all activity. If a simulation is not running, clicking on a component after KILL has been clicked will delete that component. In either case, the QUIT button must be used to leave the KILL mode.
LOAD	This button allows the user to load a network configuration. The text window appears asking for the name of the file to be loaded. Note that this erases whatever configuration was being displayed on the screen at the time.
SAVE	The SAVE control button allows the user to save the present configuration in a specially formatted text file which is readable by the simulator at LOAD time. The text window appears asking for a filename under which to save the configuration. Present values of the components' parameters are <u>not</u> saved.
SNAP	This is similar to SAVE, but in addition it saves the present arrangement of meters and information windows on the display. The text window

appears asking for a filename under which to save the configuration. Present values of the components' parameters are saved.

PRINT Prints out the network topology into a postscript file.

QUIT This is the normal exit from the simulator program. Note that clicking on the QUIT button while in KILL mode merely causes an exit from that mode; it does not cause an exit from the program.

1.5 Operating the Simulator

1.5.1 Loading a Network Configuration

There are three ways to specify a network configuration for the program to simulate.

1. Specify the name of a *configfile* describing the network on the command line. This network will be automatically loaded when the programs begins.

2. Use the LOAD command while in the simulator program. This is accomplished by clicking on the LOAD control button; a prompt will then appear in the text window asking for a file name. After the user enters the name of the file, the network configuration is loaded. Note that this erases whatever configuration was being displayed on the screen at the time.

3. Create a network while in the simulator program using the tools the program provides. Using this process, the user decides on the appropriate components, their characteristics and interconnections.

1.5.2 Creating a Network Configuration

The process of creating a network for simulation starts with the creation of components.

1.5.2.1 Creating Components. Creating components (except for links) is achieved by holding the **shift** key down and clicking the **right** mouse button on the background. The initial location of the component will be the location of the mouse when the right button is released. (Components may be repositioned after they are created; see **1.6.3.2 Moving Windows** below). After the right button is released a menu of component types will appear; this menu contains the items shown.

SWITCH
B-TE
ATM APPLICATION
ABORT

After the user clicks on the desired component type, a component information window will appear on the background. The user will be prompted (in the text window) to enter certain information about the component. The first item requested is always the component's name. Next, the user is prompted to enter values for "input" parameters, i.e., the parameters that will define the component's behavior in the network. For a comprehensive list of these parameters see **Appendix A**. After all the required parameter values are entered, the component will be created. The information window also has elements that control data display and recording; these will be discussed below.

1.5.2.3 Linking Components. After the ATM switches and B-TE components have been created they are connected into a network by creating physical links. A physical link is also considered to be a network component and has a name and parameters associated with it. A link may connect any two ATM switches or one switch and one B-TE. The procedure for creating a link is as follows:

> Select the first component to be linked by clicking on it with the **middle** mouse button while holding down the **shift** key.
>
> Select the second component to be linked by the same method. At this point a line will appear and the physical link component will be created. As with other components, an information window will appear and the user will be prompted to enter a name and some input parameters.

To complete the linking process the ATM Application components must be connected to the B-TE components. The process is like creating the physical link (**shift**, click **middle** button on component) but in this case only a line linking the components will appear, no information window. This is because this type of connection is not considered a component.

1.5.2.3 Creating Routes. A Route is an ATM Permanent Virtual Connection, a path over which the cells travel through the network. In the simulator, a Route is a list of adjacent components beginning and ending with ATM Applications. To create a Route, hold the **shift** key down and click the **left** mouse button on each component in the route. A message will appear briefly in the text window after each click to affirm (or reject) the addition of the component to the route. The first and last components in this process must be ATM Applications. When the user clicks on the final Application on the path, the route is created. Only one route going out of an ATM Application is assumed, although multiple routes may be coming in.

Performing a shift/left-click on anything other than a component aborts route creation. However, any other commands or button clicks that are not shift/left-clicks can take place at any time in the route creation process. If the user attempts to include a component in the route which cannot be included (perhaps because it is not a neighbor) it will not be included, but the route creation process will not be aborted. To abort an incomplete route creation process and start over, shift/left-click twice on the window background.

Once routes have been created they cannot be deleted. All desired routes should be created at one session, i.e., do not try to add routes to a loaded file that has been previously configured and contains routes.

CAUTION: Any attempt to start or run a simulation before routes have been created will cause a program crash.

1.6 Operational Features

The simulator provides several features which may be used to enhance the display of information, modify the network that was created, save existing configurations, and log data from the simulation runs.

1.6.1 Displaying Information about the Network

1.6.1.1 Component Information Windows. These are the same windows that appear when a component is created. They are used during the process of setting values of input parameters but may also be used to modify those values, display output parameter values, and to control data logging. The figure below is an example of an information window. The first line shows the component name, the second line an input parameter. The two shaded blocks are output parameters with current parameter values displayed. (Note: This shading does not appear on the screen).

		switch1
		Max. Output Queue Size (-1=inf): -1
		Link 1 output queue has 25 cells
		Number of cells dropped on route = 0

To bring the information window onto the screen, click the **middle** mouse button on the component's symbol; a window similar to the one above will appear. To the left of each parameter's information line are two small boxes. Clicking the **middle** mouse button on the left-hand box toggles a meter display on and off for that parameter; clicking on the right-hand box toggles data logging on and off for the parameter. The box will become white when its function is turned on and revert back to its background color when it is toggled off. The example above shows a meter created for "Link 1 output ..." and data logging selected for "Number of cells dropped ..." Both box types are valid only for output parameters; clicking on either box for any other parameter will have no effect.

When defining a component for the first time, a prompt will appear in the text window automatically, asking for the required information. Each entry is terminated by a RETURN. No other action is possible until all requested information has been entered. To modify a parameter at any other time, click the middle mouse button on the desired line. Once again the prompt will appear in the text window and the value may be entered, terminated by a RETURN. A RETURN with no entry will accept the current value.

To remove the information window from the screen, click the middle button on the component's symbol, and the information window will disappear.

1.6.1.2 Meters. To display information about a parameter in graphical form, a meter is created for that parameter. To create a meter for a particular parameter of a component, click the **middle** button of the mouse on the left-most box next to the parameter on the component's information window. This box will become white, and the meter will be created. This meter will remain on the screen even if the component's information window is not displayed. Meters are stacked below the component box whose parameters' values they display. They consist of rectangular boxes of varying lengths and heights. The location and size of the meter box can be modified by the user. (See **1.6.3.3 Resizing Windows** below.)

When a meter has been created, clicking on the meter symbol with the **middle** button will cause the following meter setup window to appear.

Meter name:
Component name:
Meter type:
Y-axis scale:
X-axis scale: microseconds
Display meter name: yes
Display scale: no
Histogram Min: 0
Histogram Max: 0
Histogram Cells: 0
Histogram Samples: 0

Select the desired line in the window by clicking on it with the **middle** button, then make the desired entry from the keyboard. The meter name may be anything the user desires. The component name is entered automatically; it is always the name of the component selected for monitoring (but it may be changed). The X and Y axis scales may or may not be adjustable, depending on the meter type. The Histogram type meter requires some additional entries. (See Meter Types in Appendix B.) "Display meter name" and "Display scale" are options that may be toggled on or off by a click on the line. When "Display scale" is on, horizontal lines will appear on the meter as the program adjusts the Y-axis scale.

BINARY METER
BAR GRAPH
LOG
TIME HISTORY A
TIME HISTORY D
DELTA METER
HISTOGRAM

When a meter is created, a type considered to be appropriate will be selected by default. The user may, however, change the meter type if so desired. To do this, click the **middle** mouse button on the Meter Type line; at this point the meter select window shown will appear. Click the **middle** mouse button on the desired line to select the type. The most desirable meter type will depend on the parameter that is to be monitored. For example, a binary meter is best for a congestion flag, a bar graph for percentage of link utilization, Time History A for packets in an output queue, etc. (See Meter Types in Appendix B for a full description of available meters.)

To delete a meter, click the **middle** mouse button on the box in the component information window used to create the meter. The meter will disappear, and the box will revert to its normal color.

Meters are not cleared at the restart of a simulation. To start with a clear meter, delete it and create a new one.

1.6.1.3 Logging Data. Data logging is a method of recording the values of a parameter while the simulation is running. Logging for a parameter is toggled on and off by clicking the **middle** mouse button on the right-hand box on the information window line for that parameter. When logging for a particular parameter is turned on, its box in the information window becomes white, and every new value of that parameter with a corresponding time stamp is saved in a file. The file is created in the current directory with the name *sim_log.xxxx* where *xxxx* is the process ID of the simulator. The file created by this process will contain an entry for every value change of every parameter that was tagged for data logging. Every entry will consist of parameter number, time tick, and parameter value at that tick. The parameter number will be identified by name in the file header.

For Switch and B-TE components, clicking on the right-hand box next to the component name in an information window results in the arrival of each cell (on n cells) into that component being logged into the sim_log file. For these components there is an input parameter, "Logging every (n) ticks," that lets the user decide on the frequency of the data logging.

When operating without X Windows (-x switch on) in addition to the sim_log file, a file named *sim_snap.xxxx* is created when the simulation is finished. This file is actually a snapshot file containing the component status and parameter values at the time the simulation stopped.

1.6.1.4 Log File Format. The following brief example shows the format of a sim_log file:

```
# 1 'switch3' 'Name'
# 2 'switch2' 'Cells in VBR Q to link22'
# 3 'switch2' 'Cells dropped in VBR Q to link22'
2 3003 1
2 3003 2
2 3043 3
1 3277 switch3 link22 4
2 4095 3
3 4175 1
```

The lines at the head of the file starting with pound sign (#) are a listing of all of the parameters that were marked for data logging when the simulator was running. The number immediately following the # is the ID number that will be used in the remainder of the file to identify the parameter. The rest of the line gives the component name and parameter name respectively.

All lines following the ones marked with # are the actual data recorded during the simulation. The first column is the parameter ID, the second column is the time (in ticks), and the third column is the value of the parameter at that time. A slightly different format is used for the case where the data logged represents cell arrival at a switch or B-TE component. (This is the logging enabled with the box on the component's name line.) In this case the third column is the name of the component on which the data is collected (switch3 in the example). The fourth column is the name of the link from where the cell arrived (link 22), and the fifth column is the route number.

1.6.2 Making Modifications

1.6.2.1 Modifying Components. After it is created, a component can be modified by editing its input parameters. To edit a parameter, pop up the component's information window by clicking on the symbol with the middle mouse button, then click on the parameter to be edited. A prompt will appear in the text window, at which time the new value of the parameter can be entered.

1.6.2.2 Deleting Components. Deleting components is done with the KILL control button. After clicking on KILL, any component that the user clicks on is deleted. When finished deleting components, the user clicks on QUIT to get out of this mode. CAUTION: Failing to click on QUIT after deleting can be harmful to your configuration; inadvertent deletion of components may result if the middle button is used for selection without QUITing the delete mode. Also note that clicking on QUIT while in KILL mode does not cause an exit from the simulator program, but a second click on QUIT will end the session.

It is not possible to delete components once they have been placed in a route (an ATM Virtual channel). Furthermore, it is not possible to delete a route, thus the user should make every effort to insure that the configuration is constructed as desired before creating the routes.

1.6.3 Manipulating the Network Display

1.6.3.1 Raising/Lowering Windows. Clicking the **right** mouse button on a window will raise (bring forward) that window so that nothing else on the display will obscure that window. Clicking the **left** mouse button on a window will lower (push back) that window so that it does not obscure any other windows.

1.6.3.2 Moving Windows. Any of the windows in the network display may be repositioned, including components, meters, and information windows. Even the control buttons and clock may be moved, but only as a group. To accomplish a move, click and hold the **right** mouse button on the window, drag the box outline which appears to the new location for the window, and release the mouse button.

1.6.3.3 Resizing Windows. It is possible to resize meter windows. To do this, click and hold the **middle** mouse button on one corner of the window. A box outline will appear which can be resized by moving the mouse with the button still depressed. When the box outline is the desired shape and size, release the mouse button and the window will be resized.

It is also possible to resize the entire simulator window. Its initial size is the full size of the screen. To change the size or location of the window, use the standard X Window manager (uwm). You must have the line *resizerelative* in your .uwmrc file for this to work, however.

1.6.3.4 Resizing Information Windows. Clicking and holding the **middle** mouse button anywhere inside the information window will cause its dimensions and text to get larger. To return to the normal size, the information window must be closed and reopened.

1.6.4 Saving a Network Configuration

There are two ways to save a network configuration.

> The SAVE command allows the user to save the present network configuration. Clicking on the SAVE control button causes the program to prompt the user for a filename under which to save the configuration.
>
> The SNAP command does the same thing as SAVE except that it also saves the present arrangement of meters and information windows on the display. The SNAP command saves the temporary values of the components' parameters.

A detailed description of the formats of both these file types is given in **Appendix C.**

1.6.5 Post Simulation Analysis using the Log File

In many cases the user will find it desirable to have data on one or more network components plotted or otherwise presented for further analysis. One way of doing this is to parse the sim_log file in order to get a data file with two columns (X, Y) that can be fed into any datasheet program such as Lotus 1-2-3, GnuPlot, etc.[2] A "filter" program is provided with the simulator package for this purpose. The usage for the filter is as follows:

> **filter sim_log.*xxxx component_name parameter_name***

---

[2] Trade names mentioned in the text are meant only to identify typical products. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply the products are necessarily the best availble for the purpose.

The above line will send the filter output to the standard output device; to redirect the output to a file type;

filter sim_log.*xxxx component_name parameter_name > output_file*

The filter program can be easily modified to do other post-processing tasks such as to change the time from ticks to milliseconds, or to obtain a throughput rate from the cell arrival data.
The figure below is an example of a parameter plot obtained by post-processing a sim_log file. This figure represents the throughput rate for a particular route that has a VBR traffic source. The measurement of interest in this case is the virtual circuit (VC) rate at the switch at the receiving end of the route on a particular link and identified with a particular route. This information was parsed out of the sim_log file and the number of such cells arriving was counted for a particular period of time. The count per unit time was then translated into Mbits/s by a simple calculation and the result plotted as shown.

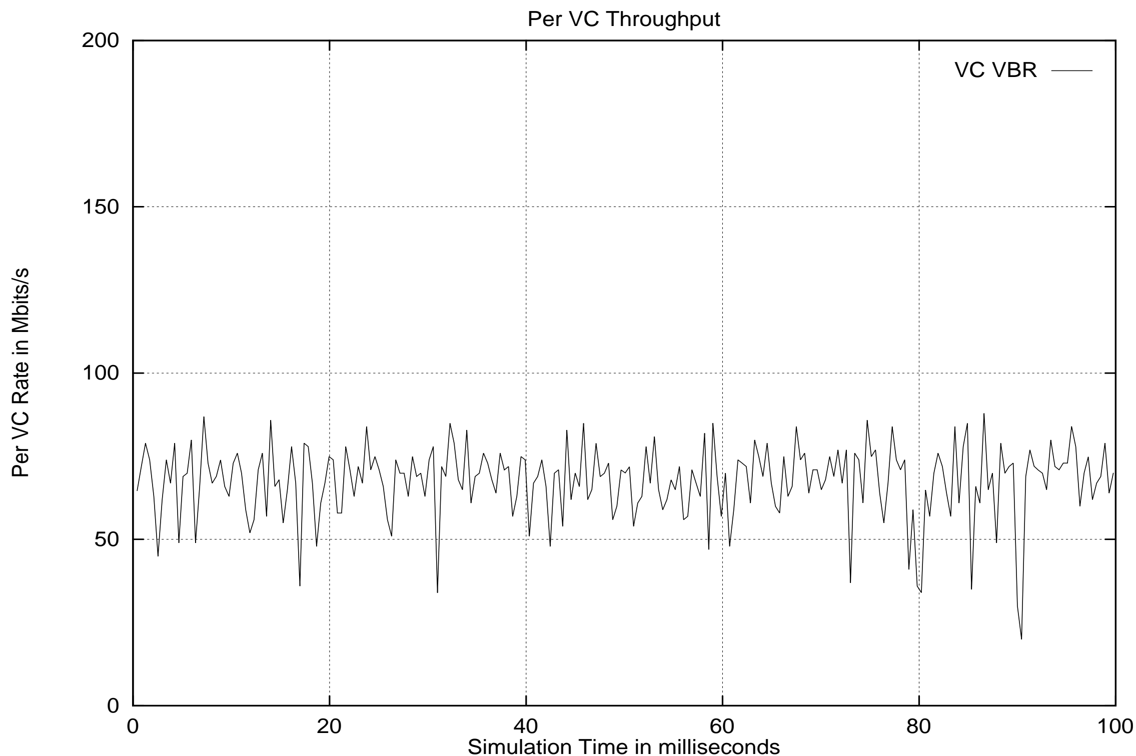


Figure 2. Sample Parameter Plot

1.7 Simulator Concepts

1.7.1 Simulation Clock

The simulator is *event* driven. Components send each other events in order to communicate and send cells through the network. The software contains an event manager which provides a general facility to schedule and send or "fire" an event. An event queue is maintained in which events are kept sorted by time. To fire an event, the first event in the queue is removed, the global time is set to the time of that event and any action scheduled to take place is undertaken. Events can be scheduled at the current time or at any time in the future. Scheduling events for the past is considered illogical. Events scheduled at the same time are not guaranteed to fire in any particular order.

Simulator time is maintained by the event manager in units of *ticks*. The time is maintained as an unsigned 32-bit value. The simulator time represented by one tick can be changed by software modification (see section 2.3.4), but not by the simulator user. For the present, a tick represents 10 nanoseconds. With that value, a total of 42 seconds of simulated time is available for one run of the program.

1.7.2 ATM Switch

The switch is the component that switches or routes cells over several virtual channel links. A local routing table is provided for each switch. This table contains a route number (that is read from incoming cell structure and is the equivalent of the cell's virtual channel identifier), a next link entry, and a next switch/next B-TE entry. Let's consider a cell arriving at the switch from a physical link. At the next switching slot time, after some delay (set by user), the switch looks in its local routing table to determine which outgoing link it should redirect the cell to. At this point, if the link has an empty slot available, the switch puts the cell on the link. If a link slot is not available, the cell awaits transmission in one of the priority queues, namely, the CBR/VBR queue or the ABR queue, depending on the type of service provided by this virtual channel. Cells in the CBR/VBR queue have priority over cells in the ABR queue, i.e., it is only when the CBR/VBR queue is empty that the ABR traffic is sent. If either queue exceeds a High Threshold value set by the user, a congestion flag for that port is set to True. Both queues must be below a Low Threshold value for the congestion flag to be reset to False. The Output Queue Size (set by the user) determines the available buffer space for each type of queue (CBR/VBR or ABR). If any queue exceeds the set limit, cells are dropped and this is recorded as a percentage of the total number of cells received by the switch. Also, there is a per port cell drop parameter recorded for each queue.

1.7.3 Broadband Terminal Equipment (B-TE)

The B-TE component simulates a Broadband ISDN node, e.g., a host computer, workstation, etc. A B-TE has one or more ATM Applications at the user side and a physical link on the network

side. Cells received from the Application side are forwarded to the physical link. If no slot is available for immediate transmission a cell queued in one of two queues, a VBR/CBR queue or an ABR queue. The user can specify the maximum output queue size; if either queue exceeds this limit cells will be dropped. The parameters that can be monitored for a B-TE are the number of cells in an output queue and the number of cells dropped at each queue. Also, the total number of cells received from the network may be monitored.

1.7.4 ATM Applications

The ATM application at the end-point of a link is a traffic generator. The traffic source emulated by this component may be a constant bit rate (CBR) source or a variable bit rate (VBR) source. Either source type may generated at one of two priority levels: a CBR/VBR level (highest priority) or the Available Bit Rate (ABR) level where cells are sent on the transmission bandwidth that is available after the higher level traffic has been sent. At each priority level there are three types of traffic generators:

1. A constant rate traffic where the user specifies the bit rate. Cells will be generated at the specified rate for the duration of the simulation.

2. Variable Bit Rate - Poisson. This type of traffic has an ON-OFF source. Both the burst period (ON) and the silence period (OFF) are drawn from an exponential distribution. The user specifies the mean burst length, the mean interval between bursts, and the bit rate at which cells are generated during the ON period.

3. Variable Bit Rate - Batch. For this traffic source the user specifies the mean number of cells generated during a burst and the mean interval between bursts.

For all of the traffic types, the user specifies the start time and the number of megabits to be sent.

Another ATM Application type that can be simulated is a TCP/IP application. See Appendix A for a list of input and output parameters.

1.7.5 Link Components

This component simulates the physical medium (copper wire or optical fiber) on which cells are transmitted. The user may choose the link speed from a list of several different standard rates. The user also specifies the length of the link. The output parameter reported by the simulator is link utilization in terms of bit rate (Mbits/s). The measurement of link rate is averaged over a period of 10 cells.

PART 2. Programmer's Guide

2.1 Objectives and Overview

This part of the document briefly describes the ATM Network Simulator Software and the procedures necessary to make user modifications, such as the creation of new components or to change the behavior of existing components. It is assumed that the reader is familiar with C Language programming techniques, conventions, and notations, and has the source code of the ATM Network Simulator available for reference.

The simulator can simulate anything that can be modeled by a network of components that send messages to one another. The components schedule events for one another to cause things to happen. The model being simulated and the action of the components is entirely determined by the code controlling the components, not by the framework of the simulator. The person who implements the components can decide how they will go about having components send messages to one another; the simulator framework only provides the means to schedule events and to communicate with the user.

The simulator program includes a graphical user interface which provides the user with a means to display the topology of the network, define the parameters and connectivity of the network, log data, and to save and load the network configuration. In addition to the user interface, the simulator has an event manager, I/O routines, and various tools that can be used to build components.

2.2 Components

The component is the basic building block of the simulator. There are different classes of components; examples are switches, physical links, terminal equipment, and ATM applications. Some classes allow different types within the class in order to accommodate the simulation of a variety of implementations. For example, an ATM application may generate traffic at a constant bit rate, or a variable bit rate that is governed by some particular distribution function.

Every component consists of an action routine and a data structure. All components of the same type share the same action routine; this routine is called for each event that happens to a component. Each instance of a component has its own data structure which is used to store information that characterizes the component plus some standard information required by the simulator for every component.

2.2.1 Classes and Types

Every component has a *class* and a *type*. A particular class of component may contain several different types of components. The following are the different classes of components currently defined and, in parentheses, the way the names appear in the source file **comptypes.h**:

- Links (LINK_CLASS)
- ATM Switches (SWITCH_CLASS)
- Broadband Terminal Equipment (BTE_CLASS)
- ATM Applications (CONNECTION_CLASS)

For now, the Link, Switch, and B-TE classes contain only one type each. Respectively, they are (as defined in **comptypes.c** and **comptypes.h**):

- Physical Link (ATMLINK)
- ATM Switch (SWITCH)
- B-TE (BTE)

The ATM Applications class, however, contains many types; these are defined as follows:

- Constant Bit Rate (CBRCONNECTION)
- Variable Bit Rate - Poisson (VBRCONNECTION)

- Variable Bit Rate - Batch (BATCHCONNECTION)
- Available Bit Rate - Constant (ABRCONNECTION1)
- Available Bit Rate - Poisson (ABRCONNECTION2)
- Available Bit Rate - Batch (ABRCONNECTION3)
- TCP/IP Application (TCPCONNECTION)

When creating a new type of component, **comptypes.c** and **comptypes.h** must be modified to contain a new constant for the new component type, and a new entry must be made in the **comp_types[]** array.

2.2.2 Component Data Structures

Each instance of a component has a data structure that is used to store any information needed by the component, as well as standard information needed by the simulator for every component. Component structures are kept in a list; the order of the list depends on the order of creation of the component. Each different *type* of component has its own structure which is defined in the header (**.h**) file for that type, but the beginning of every component structure is the same. This generic structure is as follows (actual listing can be found in **component.h**):

```
typedef struct _Component {
  struct _Component *co_next, *co_prev;  /* Links to other components in list */
  short            co_class;        /* Class of component */
  short            co_type;         /* Type of component */
  char             co_name[40]      /* Name to appear on screen */
  PFP              co_action        /* Main function, called with each event */
  COMP_OBJECT      co_picture;      /* Graphics object to be displayed on screen */
  list             *co_neighbors;   /* Points to a list of neighbors of this component */

        /*  Parameters -- data that will be displayed on the screen  */

  short            co_menu_up;      /* If true, then text window is up */
  queue            *co_params;      /* Variable-length queue of parameters */

        /* Any other info that a component needs to keep will vary */

  } Component;
```

2.2.3 Parameters

Any information about a component that needs to be displayed on the screen, logged to disk, or saved in a configuration file must be stored in a *parameter*. A parameter is a data structure that (besides storing a value) stores information needed to display, save, or load the parameter. The

information stored includes pointers to functions to convert the parameter to and from a string; the name of the parameter; and flags describing how to save and/or display the parameter. The Param structure is defined in **component.h**; for the readers convenience it is listed below.

```
typedef struct _Param   {
   struct _Param *p_next, *p_prev;        /* So that these can be put in a queue */
   char            p_name[40];            /* Name of this parameter for display */
   PFD             p_calc_val;            /* Computes a value to be displayed in a meter */
   PFP             p_make_text;           /* Makes a string containing the current value */
   PFP             p_make_short_text;     /* As above, but only the value, no text */
   PFI             p_input;               /* Routine to input this parameter */
   GRAF_OBJECT p_my_picture;              /* The graphics object to display this */
   int             p_display_type;        /* Type of meter for display */
   int             p_log;                 /* Integer associated with this param for logging */
   double          p_scale;               /* Scale to use for meters */
   struct  {                              /* Structure to store data in */
      int i;                              /* Commonly used value types */
      int vpi;                            /* Only need to use one of these types */
      double d;
      caddr_t p;
      struct  {                           /* Structure describing parameter value (if needed) */
            caddr_t p;
            int vpi;
            int i;
      } pi;
      tick_t sample;                      /* Keeps track of time parameter value was updated */
    } u;                                  /* This structure is used and maintained by the simulator */
 } Param
```

A component may have as many parameters as needed. They are stored in a doubly linked list pointed to by **co_params**. The I/O routines iterate through this list to display the parameters as described below. The action routine may reference the parameters any way it wants. In addition to the linked parameter list, there is a set of pointers in the component that point to the individual parameters. As the parameter is initialized and added to the list, the pointer is set to point to it. Then the action routine can use a named variable to refer to the parameter rather than trying to search through the list.

The actual value of a parameter is stored in a structure at the end of the Param structure. Currently, the structure has room for an integer, a double, or a pointer. A new value type can be added just by changing the definition of the structure. This value is not used by any part of the simulator except for the action routine of the component that contains the parameter. The I/O routines read and change the value only by calling one of the functions pointed to in the parameter structure.

A parameter is initialized by calling **param_init()** with arguments containing values for various fields in the parameter structure. The values for the arguments *calc_val, make_text, make_short_text*, and *input* are pointers to predefined functions in **subr.c**, which consists of a set of routines that calculate the parameter's value, display it, etc., for a variety of types of the

parameter, such as *int, double, boolean* and more. The following is a listing of the **param_init()** routine.

```
Param *
param_init(c, name, calc_val, make_text, make_short_text, input,
        display_type, flags, scale)
    Component *c;                        /* Pointer to the component */
    char *name;                          /* Name of parameter */
    PFD calc_val;                        /* Function to update the parameter value for display */
    PFP make_text,make_short_text;       /* Function to convert value to a string */
    PFI input;                           /* Function to read input string and convert into param value. */
    int display_type;                    /* Type of display: bar graph, histogram, etc. */
    int flags;                           /* How to display -- look below for details */
    double scale;                        /* Scale for meter */
```

The names of arguments listed below correspond to fields in the parameter, which in most cases have the same name, beginning with the prefix **p_**. For example, the argument *calc_val* is for **p_calc_val**, *flags* is for **p_flags**, etc.

p_calc_val This element points to a routine that is called to produce a value to be displayed in a meter. Each unit of this number represents one division on the scale of the displayed meter. For example, the function for a cell queue length parameter might return the length of the queue divided by ten, so that each division of the displayed meter represents ten cells in the queue.

p_make_text Used to generate text for parameter display, this element returns a pointer to a string. The string is expected to contain some meaningful, human-readable representation (i.e., with some sort of label) of the value of the parameter.

p_make_short_text Also returns a pointer to a string, but the string contains only the value of the parameter (no labels). Used primarily for logging data to disk.

p_input Points to a function that will read an input string from either the keyboard or from a file. This routine will convert the string to an appropriate value and store it into the parameter. This is used for the initialization of values that affect the operation of the component, and that can vary from one instance of the component to another. For example, hosts have a "Processing delay" parameter that is the time needed to process a cell.

p_display_type This element sets the default meter type for the display of parameter values. The constants are defined in **simx.h**; currently the possibilities are **BAR_GRAPH, BINARY, LOG, TIME_HISTORY, TIME_HISTORY_D**, **DELTA** or **HISTOGRAM**. Obviously, if the CanHaveMeterMask flag is not set, no value needs to be put into this element.

p_flags Contains flags that control the display. The constants (masks) are defined in the file **simx.h** with the following names:

InputMask When set, the simulator will call the function pointed to by **p_input**. Parameters that have this flag set will also have their values saved (using the **p_make_short_text** routine) when the configuration of the simulator is saved.

CanHaveMeterMask When set, the parameter can be displayed in a graphic "meter" using values pointed to by **p_calc_val.**

DisplayMask When this flag is set, the parameter will be displayed in the information window ("infowindow") that appears when the user clicks on a component. The text displayed is pointed to by **p_make_text.**

CanHaveLogMask If the parameter has this flag set, the user can cause the parameter values to be written to a file on the disk as the values change.

To update screen displays (either meters or infowindows) or to cause data to be logged to a disk file, the action routine for the parameter must call **log_param(c,p)** every time the value changes. The variables **c** and **p** are pointers to the component and parameter, respectively. (The **log_param()** function is found in the **log.c** file.)

p_scale This is a scaling factor for the meter. If **p_scale** > 0, the value returned by **p_calc_val** is multiplied by this number. The scale factor is disabled (multiplier = 1) if **p_scale** is zero.

2.2.4 Neighbors

Neighbors are stored as a list of **Neighbor** structures; this list is pointed to from component structures. Each neighbor structure contains a pointer to the neighboring component, a queue in which to store cells (if needed), a busy flag, and a pointer to a parameter to display anything that might be associated with the neighbor. The definition of the Neighbor structure is listed below; it can be also be found in **component.h**.

```
typedef struct_Neighbor {
  struct_Neighbor
                  *n_next, *n_prev;        /* Links for the list */
Component         *n_c;                    /* Pointer to the neighboring component */
  /* The next values will vary from network to network, and from component to component. For example, only
switches and hosts have queues in the current application. */
  queue           *n_pq;                   /* Queue of packets to be sent */
  short           n_busy;                  /* True if neighbor is busy */
  double          n_prev_sample;           /* Previous sample time used for utilization calculation in links */
  Param           *n_p;                    /* Index of parameter to display whatever */
  Param           *n_pp;                   /* Index of parameter to display whatever */
  Param           *n_ppp;
  list            *n_vpi                   /* List of parameters related to vpi number of the different routes */
  caddr_t         n_data;                  /* If a component wants to store arbitrary data for each neighbor, put
                                              it here. */
} Neighbor;
```

When a neighbor is added, the component must create and initialize a neighbor structure, and put it on its neighbors list. If there is some piece of information associated with the neighbor that must be displayed, a parameter structure must be allocated, initialized appropriately, and added to the queue of parameters in the component structure. See the function **b_neighbor()** in **bte.c** for an example of usage. The following is defined in **subr.c** and can be used when writing a new routine to give it the capability to add neighbors.

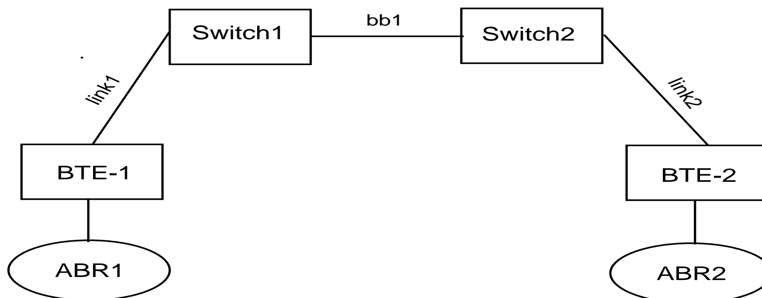
```
Neighbor *
add_neighbor(c, neighc, max_num_neighbors, num_classes)
     Component *c;              /* Comp to add neighbor to */
     Component *neighc;         /* New neighbor */
     int max_num_neighbors;     /* Max number neighbors allowed (0=infinite) */
     int num_classes;           /* How many classes follow  */
```

Similarly, the following is also defined in **subr.c** and can be used to provide a routine with the capability to remove neighbors.

```
remove_neighbor(c, neighc)
     Component *c, *neighc;
```

2.2.5 Relationship of Data Structures

Figure 3 shows the data structures that are formed when a component is created. As stated in the preceding sections, the component data structure contains the doubly-linked parameter list and a set of pointers that point to the individual components. When a neighbor is added, the component creates a neighbor structure and puts it on its neighbors list. Each neighbor structure then contains a pointer to a neighboring component. When all of the components in the network are created and linked together then "list_of_components" will be completed and will include all elements in the network topology, e.g., link1, bb1, switch2, ABR2, etc., in addition to what we see in Figure 3(b).



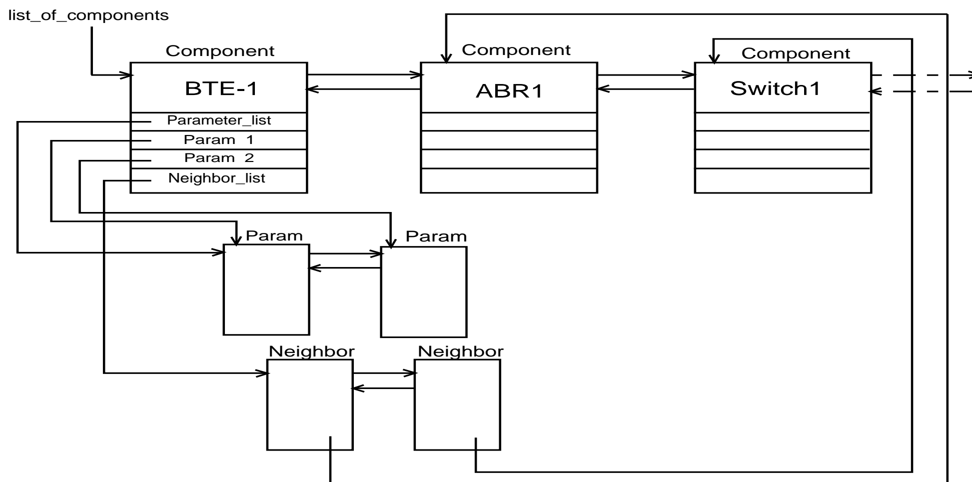


Figure 3. Creation of a Component

2.2.6 Action Routines

As previously stated, every component contains an *action routine*. This routine is called for each event that happens to a component. (Events are explained in a later section of this document.) The action routine is called (usually not by the event manager, but rather by the action routine that scheduled the event), to execute a set of commands that will give the component its unique behavior. The writer of a component can create components with any sort of behavior. Components can send any type of events to one another. However, in order to allow the simulator to do various housekeeping functions, every action routine must respond to a minimum, fixed set of commands. A synopsis of the action routine and the commands it is expected to perform is as follows:

```
/* All of these include files may not be needed, but they are the
   common ones.  */
#include <sys/types.h>
#include <stdio.h>
#include "sim.h"
#include "log.h"
#include "q.h"
#include "list.h"
#include "simx.h"          /* X window stuff & also component.h */
#include "comptypes.h"     /* The types of components */
#include "cell.h"
#include "eventdefs.h"     /* Types of events & commands defined here */
#include "event.h"
#include "this_component_type.h"
                /* ------ Definition of some Local Events, if needed -------- */
caddr_t
action(src, comp, type, cell, vpi, arg)
Component *src;            /* Component that sent this event.  Null for cmds. */
Component *comp;           /* Component to which this event/cmd applies. */
int type;                  /* Type of event or cmd that is happening. */
Cell *cell;                /* A cell. */
VPI *vpi;                  /* VPI number of data cell wherever it is applicable. */
caddr_t arg;               /* Whatever */
{
                           /* Usually a large switch statement on the event type */
}
```

An example of the "large switch statement" referred to in the last comment line above is shown in the code below which is extracted from the action routine for BTE (**bte.c**). The switch statement contains a "case" for every type of event to which the component is expected to respond. These include the events for component creation, routing, and initialization, as well as the basic function of giving the component the ability to pass cells. The example demonstrates the usual way to transmit a cell, that is, to pass it with an **EV_RECEIVE** event to another component. The transmitting component calls **ev_enqueue (EV_RECEIVE, src, dest, time, rtn, ce, arg)** which has as one of its parameters a pointer to the cell, **ce**. When the resulting event, after being queued in the event list, gets "fired," the action routine of the destination component

is called and the pointer to the cell structure is passed as an argument in that call. The destination action routine executes the portion of the code that describes the behavior of the destination component when it receives a cell. The above is still true even when no cells are passed and the component is merely sending events to itself of various housekeeping tasks.

```
switch (type) {
        case EV_RESET:                  /*  Case for receiving the command EV_RESET*/
                result = b_reset(b);    /*  Call the routine "b_reset" */
                break;
        case LINK_SLOT:                 /*  Case for receiving the private event LINK_SLOT */
                result = b_ready(b, src);  /*  Call the routine "b_ready" */
                break;
        case EV_CREATE:                 /*  Case for receiving the command EV_CREATE */
                result = b_create((char*)arg);     /* Call the routine "b_create" */
                break;
        case EV_DEL:                                    */ NOTE */
                result = b_delete(b)    /*  This pattern of calling a routine for each           */
                break;                  /*  case of an event received continues for all          */
        case EV_NEIGHBOR:               /*  of the switch statement.  When a routine is          */
                result = b_neighbor(b, (Component *)arg);
                break;                  /*  called, the portion of the code that defines         */
        case EV_UNEIGHBOR:              /*  the behavior of the BTE for that event is executed   */
                result = b_uneighbor(b, (Component *)arg);
                break;
        case EV_LEGAL_NEXT_HOPS:
                result = b_hops(b, (list *)arg);
                break;
        case EV_MAKE_ROUTE:
#ifdef DEBUG
        dbg_write(debug_log, DBG_INFO, (Component *)b,
                "processed EV_MAKE_ROUTE event");
#endif
                result = b_route(b, (list *)arg, vpi);
                break;
        case EV_START:
#ifdef DEBUG
        dbg_write(debug_log, DBG_info, (Component *)b,
                "started (a no-op)");
#endif
                break;
        case EV_RECEIVE:
                result = b_receive(b, src, cell);
                break;
        case EV_READY:
                result = b_ready(b, src);
                break;
        default:
        break;
} /* end switch statement */
```

2.3 Events

The simulator is event driven — the event queue is a queue of events kept sorted by time. To fire an event, the first event in the queue is removed, the global time is set to the time of that event, and the action routine pointed to in the event structure is called. When the user clicks on the START button, each component is sent a reset command followed by a start command, then the simulator enters a loop. The loop processes any X events, updates the display, then fires all the events at the head of the event queue that have the same time.

Currently, there are three classes of events: commands, regular events, and private events. Commands and regular events are defined in **eventdefs.h**. Commands are those events which perform some action such as reset, start, create, etc., while regular events are those which are concerned with the actual running of the simulation, e.g., receive, ready, busy. Private events are events that components send to themselves, therefore they are defined in the source files of the components, rather than in a central location.

2.3.1 Command Set (EV_CLASS_CMD)

All components must accept the following commands. The component need not actually use the command but should respond in an orderly and predictable way when the command is received. When used in an action routine, the action routine should return NULL if an error occurs during a command, and something that is non-NULL otherwise.

EV_CREATE Create a new instance of a component. The **comp** variable must be NULL, **arg** points to the name of the new component, and the action routine returns either a pointer to a new data structure or NULL for error. The action routine must allocate the correct amount of memory for the new component's data structure, create its (empty) neighbor list, create the queue of parameters, create any cell queues, etc. This command must also initialize all the private data in the component as necessary. The only information that need not be initialized are any parameters with the **InputMask** flag set. They will be initialized by the simulator as specified in the Parameters section of this document.

EV_DEL Delete an instance of component. This command will detach the component from any neighbors it has, free any storage associated with the component, including its data structure, and perform any other necessary clean-up.

EV_RESET Reset the state of the component — clear out any cell queues, forget about any cells being processed, etc. When the START button of the simulator is hit, **EV_RESET** is called first for all components and then **EV_START**.

EV_START Start operations — for example, start a cell generator sending cells. For many components, this will be a no-op.

EV_NEIGHBOR Attach another component as a new neighbor. The component to be made a neighbor is pointed to by **arg**. A component should only allow legal neighbors. For example, an ATM Application will not allow an ATM Switch to be attached as a neighbor — the ATM Application can only be connected to a B-TE (Broadband-ISDN Terminal).

EV_UNEIGHBOR Remove the neighbor pointed to by **arg** from the list of neighbors, and free any memory used to keep track of the neighbor (such as a cell queue and the neighbor structure itself). If there is a parameter associated with this neighbor, it must be removed from the queue of parameters and freed. This is a no-op if the component is not a neighbor.

EV_LEGAL_NEXT_HOPS **arg** points to an *l list* (see the section 2.5.1, Lists and Queues, for an explanation of an *l list*) that contains a virtual channel connection being constructed (not including **comp**). The list contains only the components in the path so far. **comp** is the component being considered as the next step in the connection. The action routine must return a new list of the components that are legal in the path after **comp**. A NULL list indicates an error, an empty list means that **comp** is not legal for the virtual channel connection so far, that there is no legal next virtual channel link, or that **comp** is the end of the channel. The caller will **lq_delete** the returned list after it is done with it.

This command is used by the X I/O routines to allow the user to build only legal connections. The X routines know that a component of type ATM Application must be at the beginning of a virtual channel. When the user picks an ATM Application, the X routine calls that component action routine with this command to find out which components are allowed to be next on the path. As the user picks more components, the process continues until he/she picks another ATM Application to end the path.

EV_MAKE_ROUTE This command is a no-op for some components like physical links. ATM Applications and B-TEs use it to store the route number in the VCI field of their component structures. The ATM Switch component creates a local routing table and stores the previous and next component and the VCI number of the route.

2.3.2 Regular Events (EV_CLASS_EVENT)

The following events are those which are directly involved in the running of the simulation. It is necessary to have a set of regular events that are understood by all components in order to facilitate global communication within the simulator. Additional regular events may be defined if needed. To define a new event, just put a new **#define** statement into the **eventdefs.h** file.

EV_RECEIVE Receive a cell event.

EV_READY Component ready signal.

EV_BUSY Component busy signal.

2.3.3 Private Events

Private events are events that have only local significance, i.e., they are defined within action routine for use by that routine only. Private events are the means by which an action routine can send events to itself.

2.3.4 The Event Manager

Components send each other events in order to communicate and send cells through the network. The event manager provides a general facility to schedule and send events. The primary functions of this facility are the maintenance of simulator time and the control of event queueing.

Simulator time is maintained by the event manager in units of *ticks*. Currently, ONE tick is 10 nanoseconds. Once a tick is defined in microseconds or in nanoseconds it is easy to convert this value to seconds, milliseconds, etc. To convert from ticks to microseconds, use the **TICKS_TO_USECS** macro defined in **sim.h**. To convert from microseconds to ticks, use **USECS_TO_TICKS**. Analogous macros exist for nanoseconds and full seconds (represented as doubles). The current time (in ticks) is returned by the function **ev_now()**. The time is maintained as an unsigned 32-bit value, so at 10 nanoseconds per tick a total of 42 seconds of simulated time is available for one run of the program. If longer simulation runs are required the tick definition may be changed. At ten microseconds per tick, for example, the simulator can run for almost 12 hours of simulated time. In **sim.h** there is a **typedef** called **tick_t** which has the tick definition in microseconds. For the current definition of 10 nanoseconds, the definition line is **#define USECS_PER_TICK 0.01**.

The only other event-related function that a component needs to know about is **ev_enqueue()**. This function creates a new event and places it in the event queue to be fired at the proper time. **ev_enqueue()** returns a pointer to the newly created event. The arguments correspond to the ones passed to the action routine that will receive the event. The syntax of **ev_enqueue()** is as follows:

```
Event *
ev_enqueue(type, src, dest, time, rtn, ce, vpi, arg)
    int type;              /* Type of event -- e.g EV_RECEIVE,EV_CREATE etc */
    Component *src;        /* Component which issues this command  */
    Component *dest;       /* Component on which command applies */
    tick_t  time;          /* Time at which the event should be scheduled */
    PFP      rtn;          /* The action routine of the destination component */
    Cell    *ce;           /* Pointer to a cell*/
    VPI      vpi;          /* Route number if a cell is passed */
    caddr_t   arg;         /* Can be anything */
```

Note: PFP is a Pointer to a Function that returns a Pointer, and is defined in **component.h**; **rtn** is therefore the action routine to call when the event is fired. The arguments **ce** and **arg** are optional — they may be replaced by NULL if no cell is being sent and no information needs to be passed.

You may schedule events at the current time or at any future time. (Scheduling events for the past is considered illogical.) There is no control over the order, e.g. FIFO or LIFO, of execution of events that are scheduled to fire at the same time. Hence, events scheduled at the same time are not guaranteed to fire in any particular order.

There also exists a function to *unschedule* events, i.e., remove events from the queue. Selection of events to be removed may be done according to source and destination components and type, or according to a particular event expiration time.

```
void
ev_dequeue_by_comp_and_type(src, dest, type)
    Component *src, *dest;
    Evtype type;
{
  /* Remove from the queue any subset of events with particular
     source and destination components and type.
     A NULL source or destination matches all components. */
}

void
ev_dequeue_by_time(t)
    tick_t t;
{
  /* Remove from the queue all events due to expire at a particular time t. */
}
```

Again, it should be noted that the designer of components for the simulator is free to use whatever convention he/she desires for communication between components. The simulator just provides the ability to send events — what the events mean is up to you. See the section on **Components** for the conventions now used.

2.4 ATM Network-Related Issues

2.4.1 ATM Cell Definition

Since the simulator is designed to simulate ATM networks, a *cell* data type has been defined. A cell constitutes a very important data type in the simulator because it contains the route number needed for routing by ATM switches. A cell is a data structure, defined in the file **cell.h**. The structure may contain different elements to tailor the cell for different applications, but must always contain the route number. For switching or routing purposes, an ATM switch reads off the route number found in the cell, then looks up its routing table to forward the cell via the next link to the next switch (or to the next B-TE if at the end of a connection).

The cell data structure is not constrained to be any particular format. Of course, if you are only modifying some existing components you should not remove any elements from the structure, but if you are writing a set of components from scratch, a cell can contain anything. To change the contents of a cell, just change the definition in **cell.h** and recompile. The following is a simple example of a cell structure:

```
typedef struct_Cell {          /* Define cell structure */
struct _Cell *cell_next;       /* Pointer for use by the queue the cells will be stored in */
VPI vpi;                       /* Route number (virtual path identifier) */
PTI pti;                       /* Payload type identifier */
struct cell_payload {          /* Structure for the payload portion */
Packet *tcp_ip_info;           /* The payload will */
AAL5_Trailer len;              /* be any one of    */
RM rm;                         /* these three types */
} u;                           /* Structure */
} Cell
```

An event may include a cell, and most simulation events (as opposed to housekeeping commands) do so. Normally, cells are transmitted from one component to another by having the transmitting component call a routine (**ev_enqueue**) which creates a new event and places it in a queue to be fired at the appropriate time. The receiving component must be able to process the event in order to receive the cell. This process is explained in more detail in the Events section of this document.

A module to handle the allocation and deallocation of cells is provided in the package. The module keeps track of all the cells, so that when the simulator is reset all cells can be freed in one step. **cell_alloc()** returns a new cell, **cell_free()** frees a cell, and **cell_free_all()** frees all cells.

The simulator obeys the convention that all components must dispose of all cells that they receive in one way or another. In other words, a component that receives a cell must either call **cell_free**() on the cell <u>or</u> send the cell to someone else, but not both. Furthermore, a component that sends a cell to someone else should no longer refer to that cell. If it wants to save the cell

for some reason (if the cell might be retransmitted, for example), the component must call **cell_alloc()** and make a copy of the cell.

2.4.2 Setting Up the ATM Virtual Channel

The simulator implements static connections. An ATM channel begins and ends with a component of the type **ATM APPLICATION**. A particular Application can have a route to only one other Application. When the user clicks on an ATM Application that is at the other end of the virtual channel (this is done while making the route), the routing table at each ATM Switch is updated and information about the next link and the next ATM Switch found on the path is stored.

The file **route.c** contains a couple of functions to manipulate connections. To determine where to route a cell next, the function

```
Route_info *
rt_lookup(some arguments)
/* ..
*/
```

can be called from an ATM Switch action routine; this should return the next link and next switch. The routing process starts when **io()** within **IO.c** calls **make_route_event_handler(bevent)** which is found in **route.c**. The routing process involves creating a **route_list**, which is a list of components. When finally the user clicks on a component of type **ATM APPLICATION** which is at the end of a route, all switches found in **route_list** call their respective **action_routine**s to update their local routing modules.

2.5 Tools

2.5.1 Lists and Queues

Lists (doubly-linked lists) and queues (singly-linked lists) are used extensively throughout the simulator. Lists and queues contain variables to store the current, maximum and minimum length of the list/queue. A list has the following structure:

```
typedef struct  list    {               /* list header */
        l_elt   *l_head;                /* first element in list */
        l_elt   *l_tail;                /* last element in list */
        int     l_len;                  /* number of elements in queue */
        int     l_max;                  /* maximum length */
        int     l_min;                  /* minimum length */
} list;
```

An element in the list, **l_elt**, has the following structure:

```
typedef struct  l_elt   {                       /* list element */
        struct  l_elt   *le_next, *le_prev;     /* Links */
        caddr_t le_data;
} l_elt;
```

Because both lists that were efficient and lists that were flexible were needed, there are two kinds of lists. One kind requires that the item being placed on the list contain the pointers needed to link it into the list. This means that no extra memory is needed to put the new item into the list. However, this also means that the item being placed on the list must include room for one or two pointers at the beginning, and it can only be on one list at a time. Since the item itself contains the pointers, the pointers for the first list will be overwritten when it is placed on a second list. This type of list we have chosen to call an *le list* (or a *qe queue*). The *le* stands for *list element*, and it means that the items being placed in the list already have the pointers for a list element built in. As an example, the global list of components is an *le list* and the component structure contains two pointers (the structure elements **co_next** and **co_prev**).

The other kind of list allocates a small area of memory in which to store the pointers every time a new element is added to a list. This means that adding and removing items from the list is slower, but any type of data structure (even ones that don't have pointers at the beginning) can be placed on any number of lists any number of times. This type of list is called an *l list* (or a *q queue*).

Functions (and macros) that start with **le_** and **qe_** are the faster routines, and the ones that start with **l_** and **q_** are the more general ones. (With one exception: **l_create()** serves both types of list.) In the arguments to the functions, **l** and **q** indicate a list and a queue, respectively, and any other arguments are elements on which to operate. Here is a summary of the available list and queue commands:

l_create() — Create a new, empty list and return it. Returns NULL on error.

l{e}_addh(l, elt) — Add **elt** to the head of the list **l**. The **le** version does not return anything (it is a macro); the **l** type returns NULL on error (couldn't allocate memory to hold the pointers), non-NULL otherwise.

l{e}_addt(l, elt) — As above, but add **elt** to the *tail* of the list **l**.

l{e}_remh(l) — Remove the item at the head of the list and return it.

l{e}_remt(l) — Remove the item at the tail of the list and return it.

l{e}_adda(l, prev, new) — Add **new** to the list after **prev**, which must already be in the list. Again, the **le** is a macro that doesn't return anything, and **l_adda()** returns NULL on error.

l{e}_del(l, elt) — Delete **elt** from the list **l**.

l_find(l, elt) — Search for **elt** in the list. Returns a pointer to the **l_elt** that contains **elt**. An **l_elt** is the structure that contains the pointers used to add something to an *l list*. See **list.h** for the definition.

lq_delete(l) — This function works for both lists and queues. It also works for both flavors of each, although the effect is slightly different. For **le** lists, **lq_delete()** frees the list and the elements that were stored in the list. For **l** lists, the function does not free the items stored in the list, just the list and associated extra garbage.

lq_clear(l) — As with **lq_delete()**, this function works for both lists and queues. This function removes all the items from a list or queue. If it is a **le** list or **qe** queue, the memory for the items is also freed, otherwise they are merely removed from the list or queue.

l_obliterate() — This function is only for **l** lists. It frees the list, the **l_elt**s used by the list, and the data blocks (which must have been allocated using **malloc()** or **calloc()**).

The following functions perform the same actions on queues as the similarly-named functions for lists:

q_create()
q{e}_addh(q, elt)

q{e}_addt(q, elt)
q{e}_adda(q, prev, new)
q{e}_del(q, elt)
q_find(q, elt)

Finally, queues have the following operations of their own:

q{e}_deq(q)	Removes and returns the item at the head of the queue.
qe_find(q, qe)	Looks for the item **qe** in the queue. Returns **qe** if found, NULL otherwise.
qe_dela(q, prev)	Removes the element after **prev** in **q**. This operation is *O(1)*, unlike **q{e}_del**() which is *O(n)*.

2.5.2 Other Tools

In addition to lists and queues, the simulator includes a hash table module and a module to control allocation of fixed-size memory blocks. The functions for these modules are contained in **hash.c, hash.h, mempool.c**, and **mempool.h**.

The hash table is fairly straight-forward. Its functions are described in comments at the beginning of **hash.c**.

The "mempool" was originally written to try to speed up the simulator by avoiding **calloc()** and **free**() calls. However, no real speed advantage was noted. This module is still useful though, because it makes it possible to free all allocated memory chunks with one call. Cells and events are allocated using this module, and of course anyone else may use it as well. The functions of the mempool module are relatively easy to understand and are described at the beginning of **mempool.c**.

2.5.3 Debugging

There are several ways to do debugging. There are two ways that are convenient to use with the simulator:

- Include additional code for debugging which is enclosed between **#ifdef DEBUG ..... #endif DEBUG**, define the flag **DEBUG** for the C-compiler, and set the debug-level by **dbg_set_level(DBG_ERR)** or **dbg_set_level(DBG_INFO)** to trace certain actions.
- The arrival of cells at a certain component can be recorded by calling **log_a_cell(c, p, ce)** defined in **log.c**. In order to properly print the contents of a cell, it might be necessary to modify this function according to the type of cell that is displayed.

2.6 Creating New Versions

To create a new version of the simulator by adding your own component to it, all you need is **libsim.a**, any simulator header files that your new component needs, **comptypes.c**, and the source to your component.

In brief, you must take the following steps to create a new type of component. (It is assumed that you have already built the simulator library **libsim.a** and the executable with the distributed components to make sure that it all works.)

1. Modify **comptypes.c** and **comptypes.h** to contain a new constant for the new type of component, a new entry in the **component_types[]** array, and a declaration of the action routine.

2. Create a new component structure, putting it in its own .h file, say **newcomp.h**. The easiest way to do this is to look at one of the existing component structures and modify it as necessary. Be sure to read **component.h** for a description of the common component structure that all simulator components must share. This shared part of the structure must exist and be the same for all components. Parameters and the private part of the structure can be modified as desired.

3. Create an action routine for the component. Again, the easiest way to do this is to use the code from an existing component as a model. Also see the descriptions in this document of the various commands that an action routine must perform. If the new component will interact with the components that are already written, it must deal with the events that they will send it, and it must send them events that they are expecting. Otherwise, it can act in whatever way it wants.

4. Add an object picture (or choose one from among the object pictures provided). When a component is created the routine **create_component** (found in **edit.c**) is called from **IO.c**. This routine, given the type of component to be created, will call the appropriate routine to draw the component on the screen. To change the shape of the component, one needs to write the routine that will draw the component (for example, see **pop_comp_window** in **components.c**).

5. Change the **Makefile**, to make sure the new components are compiled and linked into the simulator. For a simple component, it should suffice to add **newcomp.o** to the **ADDLOBJS** macro in the makefile. In fact, the following command line should be able to build a new simulator without modifying the Makefile:

   make ADDLOBJS=newcomp.c custom_sim

   If you want dependencies on header files and/or any special rules for making your new component, you will have to change the makefile.

APPENDIX A: Parameter Information

The purpose of this appendix is to present detailed information about ATM system parameters that the user is required to define as inputs or monitor as simulator outputs.

In all the information windows, *name* appears on the first line. The user may choose any name desired for the component, but it is helpful if the name has some relation to the component type, e.g., *link1, bte2*, etc. As soon as the name is entered it will appear on the first line of the information window and inside the component symbol.

The figures in this appendix designate output parameters by shading; this shading does not appear on the actual screen. It is not possible to enter information on the lines that are designated for outputs. Similarly, it is not possible to select an input for metering or data logging.

The window that appears when a component is first created does not necessarily have any of the output parameters that are shown here; these are added automatically when the components are all linked together in a network.

A.1 ATM Switches

		Name:
		Delay to process a cell (usec): 0
		Slot time (Mbits/sec): 0
		Output queue size (cells, -1=inf): 0
		High Threshold, Q cong. flag (cells): 0
		Low Threshold, Q cong. flag (cells): 0
		Logging every (n ticks) (e.g., 1, 100): 0
		Cells received: 0
		Percent cell drop: 0
		Cells in VBR Q to link n: 0
		Cells dropped in VBR Q to link n: 0
		Cells in ABR Q to link n: 0
		Cells dropped in ABR Q to link n: 0
		Congestion for link n: FALSE

Delay to process a cell. An increment of time after the arrival of a cell at the switch before the switch places the cell on the outgoing link.

Slot time. The rate at which cells are switched from an input port to an output port. The program calculates the cell slot time from the bit rate entered. The actual switching of a cell from input port to output port occurs at the beginning of a slot period.

Output queue size. Available buffer space for a queue; the same value is used for every queue in the switch. When a cell is ready for transmission but a slot on that link is not available it waits in a queue at that port.

High Threshold, Q congestion flag. If the number of cells in any queue exceeds this value the congestion flag is set.

Low Theshold, Q congestion flag. The congestion flag is cleared when the number of cells in all queues fall below this value.

Logging every n ticks. If n is set to 1, data will be logged for a parameter anytime there is a change in its value. Potentially, this could occur at every tick. Since this may result in an extremely large data file, it may be desirable to set n to a larger number. For example, if n = 100, logging will occur only if a change occurred and 100 ticks had gone by since the last logging activity.

Cells Received. Total number of cells received by the switch.

Percent cell drop. Number of cells dropped by the switch as a percentage of the total cells received.

Cells in xBR Q to link n. Cells awaiting transmission in a given priority queue. There are two types of queues for each port - a CBR/VBR queue and an ABR queue. Cells in the CBR/VBR queue have top priority; a cell from the ABR queue will be sent only if the CBR/VBR queue is empty.

Cells dropped in xBR Q to link n. Cells dropped at a port when a queue exceeds its maximum size.

Congestion for link n. There is one congestion flag for each port. The flag is set when a queue exceeds its High Threshold value, cleared when both queues fall below the Low Threshold.

A.2 Broadband Terminal Equipment (B-TE)

Unlike a switch, there can be only one physical link attached to a B-TE component. Cells received from the Application side (there may be multiple Applications) are queued in one of two priority queues if no link slot is available for transmission. If either queue exceeds its size limit cells will be dropped.

		Name:
		Max. Output Queue Size (-1=inf): 0
		Logging every (n ticks)(e.g., 1, 100): 0
		Cells Received: 0
		Cells in VBR Q to link n: 0
		Cells dropped in VBR Q to link n: 0
		Cells in ABR Q to link n: 0
		Cells dropped in ABR Q to link n: 0

Maximum Output Queue Size. Available buffer space for each type of queue.

Logging every n ticks. If n is set to 1, data will be logged for a parameter anytime there is a change in its value. Potentially, this could occur at every tick. Since this may result in an extremely large data file, it may be desirable to set n to a larger number. For example, if n = 100, logging will occur only if a change occurred and 100 ticks had gone by since the last logging activity.

Cells Received. Total number of cells received by the B-TE.

Cells in xBR Q to link n. Cells awaiting transmission in a given priority queue. There are two types of queues - a CBR/VBR queue and an ABR queue. Cells in the CBR/VBR queue have top priority; a cell from the ABR queue will be sent only if the CBR/VBR queue is empty.

Cells dropped in xBR Q to link n. Cells dropped at the network port when a queue exceeds its maximum size.

A.3 ATM Applications

CBR
VBR (Poisson)
VBR (Batch)
ABR (Constant)
ABR (Poisson)
ABR (Batch)
TCP/IP
ABORT

Creation of an Application component results in the appearance of this menu window since there are several types of such components. Selection of a type will result in the appearance of one the information windows shown below.

For these information windows, the shaded line is not an output parameter; it is the name of the ATM Application at the other end of the route. The name is filled in automatically when the route is created.

All ATM Applications have an input parameter labeled *Start Time*. This is the number of microseconds after the program starts that the Application will begin generating cells. By setting the start time to a different value for each Application the user can ensure that they all do not start at once.

Constant Bit Rate (CBR) Information Window

		Name:
		Bit Rate (Mbits/sec): 0
		Start time (usec): 0
		Number of Mbits to be sent: 0
		Other End Connection: Name

Cells are generated at a constant rate for the duration of the simulation.

Variable Bit Rate (VBR) (Poisson) Information Window

		Name
		Bit Rate (Mbits/s): 0
		Mean Burst Length (usecs): 0
		Mean Interval Between Bursts(usecs): 0
		Start Time (usecs): 0
		Number of Mbits to be sent: 0
		Other End Connection: Name

Traffic is generated as an ON - OFF source. Cells are generated at the specified bit rate during a burst. Mean burst length and mean interval between bursts are user specified, but the actual periods of both are drawn from an exponential distribution.

Variable Bit Rate (VBR) (Batch) Information Window

		Name
		Mean Number of cells generated: 0
		Mean Interval Between Bursts (usec): 0
		Start time (usec): 0
		Number of Mbits to be sent: 0
		Other End Connection: Name

The user specifies a mean number of cells that are to be sent in each burst and the mean interval between bursts; the actual numbers are drawn from an exponential distribution. Bit rate is not an input; the number of cells to be transmitted are ready to be sent as a "batch" by the time burst interval begins.

The input parameters for the Available Bit Rate Applications are exactly like their CBR/VBR counterparts.

Available Bit Rate (ABR) (Constant) Information Window

		Name
		Bit Rate (Mbits/sec): 0
		Start time (usec): 0
		Number of Mbits to be sent: 0
		Other End Connection: Name

Available Bit Rate (ABR) (Poisson) Information Window

		Name
		Bit Rate (Mbits/s): 0
		Mean Burst Length (usecs): 0
		Mean Interval Between Bursts(usecs): 0
		Start Time (usecs): 0
		Number of Mbits to be sent: 0
		Other End Connection: Name

Available Bit Rate (ABR) (Batch) Information Window

		Name
		Mean Number of cells generated: 0
		Mean Interval Between Bursts (usec): 0
		Start time (usec): 0
		Number of Mbits to be sent: 0
		Other End Connection: Name

TCP/IP Information Window

		Name:
		Bit Rate (Mbits/sec): 0
		Buffer Size (bytes): 0
		Transmitter's State: FALSE
		Start Time (usec): 0
		Start Random Period (sec): 0
		Transmission Size (bytes): 0
		Number of bytes unsent: 0
		Sender sequence number logging
		Sender ACK sequence number logging
		Receiver sequence number logging
		Mean packet processing time (usec): 0
		Packet processing time variation (usec): 0
		TCP open time (usec): 0
		TCP close time (usec): 0
		Connection Busy: FALSE
		Packet input queue has 0 pkts
		Max segment size (octets): 0
		My Receive Window size (octets): 0
		Peer Receive Window size (octets): 0
		RTT (usecs): 0
		RTO (usecs): 0
		RTO (current): 0
		Average throughput (bytes/sec): 0
		Retransmission percentage: 0
		Other end connection: Name

The TCP/IP Application sends data in large packets. These packets must be segmented to fit into the ATM cell structure before being put on the network. A rather extensive set of parameters are provided that give the user flexibility in controlling and monitoring this type of application.

Input Parameters.

Bit Rate. The bit rate for the cells on the ATM route.

Buffer Size. The size of the user's buffer, large enough to hold many packets, but a fraction of the total transmission size.

Transmitter's State. A TRUE/FALSE control. If FALSE, no transmission will take place, but the Application can still receive.

Start Time. When this is a positive number, it is the number of microseconds after the program starts that the Application will begin to generate traffic. If a negative value is placed here the Random Start feature will be activated (see below).

Random Start Period. If Start Time is negative, the value entered here is the mean for a random start time.

Transmission Size. The total number of data bytes (payload) to be sent.

Mean Packet Processing Time. The mean delay to process the packet.

Packet Processing Time Variation. A computation based on a random perturbation in the processing delay in the range [-Packet Processing Time Variation, +Packet Processing Time Variation].

Maximum Segment Size. The maximum size of the TCP/IP packet, whether it is being sent or being received.

My Receive Window Size. This number determines how many packets are going to be sent without waiting for an acknowledgment.

Output Parameters

Number of Bytes Unsent. This is the number of bytes remaining from the total specified under *Transmission Size.*

Every TCP/IP packet has a sequence number, including the ACK packets. The following three parameters let the user enable the logging of these numbers as the packets are sent or received. Note that only the logging function applies, no metering is possible.
Sender Sequence Number Logging
Sender ACK Sequence Number Logging
Receiver Sequence Number Logging.

TCP Open Time. The time that the first TCP packet was sent.

TCP Close Time. The end of the TCP transmission (all bytes have been sent).

Connection Busy. Activity flag for TCP processing; TRUE = busy, FALSE = not busy.

Packet input queue has *n* packets. This queue contains packets waiting for TCP processing, both for transmission (before segmentation) and for reception (after reassembly).

Peer Receive Window Size. This is the other-end companion to *My Receive Window Size.*

RTT. Round Trip Time - time from packet sent to ACK received. This is set to a default value at the beginning of a simulation run, then actual measurements are made and Jacobson's[3] algorithm is used to "smooth" the result.

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[3]Jacobson, V., "Congestion Avoidance and Control", *Proceedings of the ACM SIGCOMM '88*, August 1988.

RTO. Retransmission Time Out - the time interval to wait before deciding an unacknowledged packet has been lost. At the start of a simulation this is set equal to RTT (a default value) then, as measurements of RTT are accumulated, Karn's exponential backoff multiplier is incorporated to calculate this parameter.

RTO (current). This is the Retransmission Time Out interval currently being used.

Average Throughput. This is based on the average number of packets **successfully** transmitted.

Retransmission Percentage. Retransmissions as a percentage of total packets sent.

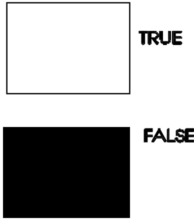
A.4 Link Components

		Name
		Link Speed (Mbits/sec): 0
		STS-1 51.840 Mbits/sec
		STS-3C 155.520 Mbits/sec
		STS-12C 622.080 Mbits/sec
		STS-24C 1244.160 Mbits/sec
		DS-3 44.736 Mbits/sec
		ATM-F Multimode Fiber 100 Mbits/sec
		Distance (km): 0
		Link Rate (Mbits/sec) to Switch n: 0
		Link Rate (Mbits/sec) to B-TE n: 0

There are only two input parameters for a Physical Link, link speed and distance. The link speeds shown in the window are not selectable with the mouse; the desired speed (in Mbits/s) must be typed into the text window. However, the bit rate typed in need not be exact; the software will accept a round number near the standard rate and make the necessary adjustment. The bit rates shown include overhead bits. The simulator maps the entry into the correct payload rate when doing calculations for bits transmitted. One exception: if the entry is less than 40 Mbits/s, the entered rate is accepted directly with no mapping.

The link output parameter is link utilization (in each direction) in terms of bit rate (Mbits/s).

APPENDIX B: Meter Types

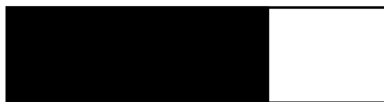


BINARY METERS

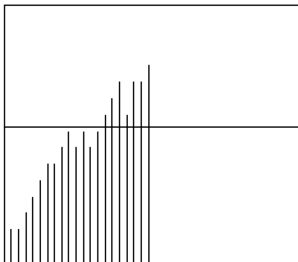
The Binary meter type is most useful for true/false indicators such as flags. If assigned to a parameter with numerical values, the rectangle will be shaded with one of five colors to differentiate it from a binary parameter.

BAR GRAPH

This meter consists of a horizontal bar whose length is proportional to the parameter value. This type is most useful for parameters that are expressed as a percentage of some maximum value. The Y-axis scale setting applies to the horizontal dimension in this case. In the example shown, if the Y-axis scale is 100, then the value indicated is approximately 40. The X-axis scale for this meter is undefined and cannot be set. (This reversal of axes is unintended; it will be corrected in future versions.)

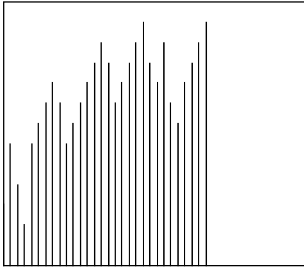

LOG BAR GRAPH

The log meter type is like the bar graph except that the horizontal scale is logarithmic. Like the bar graph, the Y-axis scale setting applies to the horizontal dimension. In the example shown, if the Y-axis scale is 10, the value indicated is approximately 5. The X-axis scale is undefined and cannot be set.


TIME HISTORY A

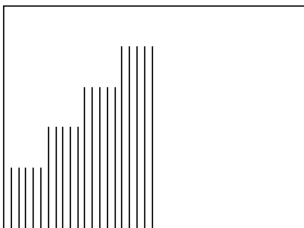
The TIME HISTORY A meter displays parameter values that have been averaged over an interval of time. When setting the X-axis scale, the user is asked to enter a sampling interval (in microseconds). This is the minimum interval between lines drawn on the screen, i.e., the minimum update interval. The meter will not be updated unless the parameter value is changing. When an update does occur, the value is the average value since the last update.

The Y-axis scale is set by the user, but the full scale range will be adjusted by the program as necessary. For example, if the user sets the Y-scale to 1000 and the parameter values begin to exceed 1000, the full scale range will be doubled to 2000. A horizontal line will be drawn at the midpoint of the meter to indicate the scale change. This process of doubling the range will be repeated as often as necessary, resulting in many horizontal lines on the face of the meter. The vertical distance between these lines will always represent the Y-axis value set by the user.



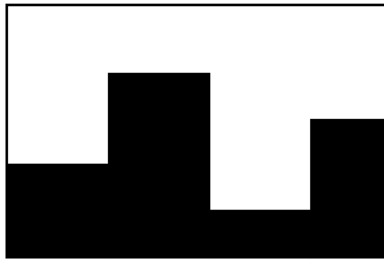
TIME HISTORY D

The TIME HISTORY D meter is similar to the A type, but the update of the meter occurs every time the parameter value changes. The value displayed is the actual value of the parameter and not an average. Since X dimension of the meter is dependent on the rate of change of the parameter, the X-axis scale cannot be set by the user. The Y-axis scale behavior is the same as for the TIME HISTORY A meter.



DELTA

The Delta meter type indicates the absolute value of the change in the value of a parameter. The meter is updated every time a change occurs. Since the X dimension of the meter is dependent on the rate of change of the parameter, the X-axis scale cannot be set by the user. In this example, the Y-axis scale is 5; the parameter value changes by an increment of one several times, then two several times, then three, etc. The Y-axis scale behavior is the same as for the TIME HISTORY A meter.



HISTOGRAM

To use the Histogram meter the user must make four entries in the meter setup window:

Histogram Min:
Histogram Max:
Histogram Cells:
Histogram Samples:

Histogram Min and Max define the X-axis range of the meter. The value of Histogram Cells determines how many cells (or "classes") the histogram will have. The total number of samples to be included in the figure is entered in Histogram Samples. The Y-axis represents the number of occurances of the parameter value in the specified range. For example, if Min = 0, Max = 100, Histogram Cells = 4, and Histogram Samples = 50, then the meter is divided into four cells representing value ranges of 1-25, 26-50, 51-75, and 76-100. Occurances of 10, 20, 5, and 15 in these ranges, respectively, will result in a figure like that shown. The total Y-axis scale is 50, the same as the total number of samples included.

APPENDIX C: Configuration File Formats

Network configurations that have been created with the simulator program may be saved in files for future use. The SAVE and SNAP commands, described briefly in sections 4.3.3 and 6.4, are used to create these files. This appendix gives a detailed description of the file formats.

C.1 Format of the SAVE file.

The SAVE file conserves information about the components, including their screen position, the values of their input parameters, their interconnection with neighboring components, and the established routes (virtual circuits). Note that it does not preserve values of output parameters, status of information windows, meters, or data logging instructions; for these features use the SNAP file described below.

The listing below is an example of a SAVE file. There are three distinct types of information in the file - component descriptions, linkages, and route definitions.

The component descriptions come first. The first line of each description begins with the keyword *component*, followed by the component's name in single quotes, then the component type in capital letters, and finally the x and y coordinates of the screen position of the component. The lines immediately following are a listing of the input parameters and their values. Any text on a line after a pound sign (#) is a comment; the comment identifies the parameter.

Following all the component descriptions are the linkages. Each line of this group begins with the keyword *neighbor1*, followed by a component's name in single quotes, and then either a physical link name or another component name in single quotes. In the example, 'switch1' has two physical links attached, while the B-TE named 'host1' is connected to the ATM Application named 'tcp1'.

The last group of lines in the file is the route listing. Each line begins with the keyword *route1*, which is followed by the names of all components in the route. Each component name is in quotes. The component list always begins and ends with an ATM Application component.

Sample SAVE file:

```
component 'switch1' SWITCH 417 341
param 'switch1'  # switch
param 0 # Delay to process a cell (uSec): 0
param 155        # Switching Slot time (Mbit/s): 155
param 10000      # Output q_size (cells, -1=inf): 10000
param 550        # High Threshold for Q Congestion Flag: 550
param 450        # Low Threshold for Q Congestion Flag: 450
param 1 # Logging every (ticks) (e.g., 1, 100): 1
```

```
component 'host1' BTE 331 452
param 'host1'    # host1
param 50         # Max Output Queue Size(-1=inf): 50
param 1 # Logging every (ticks) (e.g. 1, 100): 1

  .
  .
  .

neighbor1 'switch1' 'link1'
neighbor1 'switch1' 'link2'
neighbor1 'host1' 'tcp1')

  .
  .
  .

route1 'tcp1' 'host1' 'link1' 'switch1' 'link2' 'host2' 'tcp2'
```

C.2 Format of the SNAP File.

The SNAP file contains all the configuration information of a SAVE file plus additional information that reveals the status of the simulated network at a particular point in time, i.e., when a "snapshot" of the simulation has been made.

At the top of the file are two lines starting with the pound sign (#). The first line records the seed used for that particular simulation run. (This line will not be loaded or used if the file is used as a configuration file.) The second line records the time (in ticks) when the snapshot was taken.

Following the two lines starting with the pound sign is a listing of all the components in the network. The format of the component listing is the same as for the SAVE file, but with some additions. If component had an open information window when the snapshot was taken, the keyword *infowindow* appears immediately after the line with the *component* keyword. Next comes the input parameter listing, each line beginning with the word *param* and followed immediately with a number indicating the parameter's value. Following the value are two other numbers. The first number indicates whether or not the log box is active; any number between 0 - 41 means it is inactive, 42 -77 indicates an active log box. (For input parameters, an active log box means that the parameter line will be recorded once in the log file. The box can only be activated by changing this number in the SNAP file, not by clicking on the box in the window.) The final number on these lines is unused and is always a zero.

Following the *param* lines is a list of all output parameters, each line beginning with the keyword *pflags*. The text on each of these lines following the pound sign is a comment that contains the parameter description and value. (Output parameter values are not used when the SNAP file is used as a configuration file.)

On each output parameter line, following the *pflags* keyword, there is a 2 or a 4 with the letter 'a' or 'b' appended. This is a code that reveals whether the output parameter has its data logging box in the active mode, and/or its meter window open. The different combinations are as follows:

2a = the log box is not active, the meter window is closed.
2b = the log box is active, the meter window is closed.
4a = the log box is inactive, the meter window is open.
4b = the log box is active, the meter window in open.

Following the above is another entry consisting of a single digit with the value of 1 through 7. This digit represents the type of meter used for the graphical display. The types are identified as follows:

1 = Binary meter
2 = Bar graph
3 = Log graph
4 = time history A
5 = time history D
6 = Delta meter
7 = Histogram

If the meter window for an output parameter is open, the coordinates of its position on the screen and its dimensions are given immediately following the meter type entry. For example, for the line *pflags 2b 4 562 424 159 93*, the x and y coordinates of the window are 562 and 424, and 159 and 93 are the height and width, respectively.

The remainder of the SNAP file contains linkage and route definition; these are in a format identical to the SAVE file.

Sample SNAP file:

```
# Seed 776093072
# Time of snapshot (ticks) 0
component 'switch1' SWITCH 417 341
infowindow
param 'switch1' 32 0      # switch1
param 0 12 0    # Delay to process a cell (uSec): 0
```

```
param 155 12 0  # Switching Slot time (Mbit/s): 155
param 10000 12 0         # Output q_size (cells, -1=inf): 10000
param 550 12 0  # High Threshold for Q Congestion Flag: 550
param 450 12 0  # Low Threshold for Q Congestion Flag: 450
param 1 12 0    # Logging every (ticks) (e.g. 1, 100): 1
pflags 2a 4      #Cells Received: 0
pflags 2a 4      #Cell Drop %: 0
pflags 2a 4      #Cells in VBR Q to link1: 0
pflags 2a 4      #Cells dropped in VBR Q to link1: 0
pflags 2a 4      #Cells in ABR Q to link1: 0
pflags 2a 4      #Cells Dropped in ABR Q to link1: 0
pflags 2a 1      #Congestion for Link link1: FALSE
pflags 2a 4      #Cells in VBR Q to link2: 0
pflags 2a 4      #Cells dropped in VBR Q to link2: 0
pflags 2a 4      #Cells in ABR Q to link2: 0
pflags 2a 4      #Cells Dropped in ABR Q to link2: 0
pflags 2a 1      #Congestion for Link link2: FALSE


component 'host2' BTE 562 460
param 'host2' 32 0      # host2
param 50 12 0   # Max Output Queue Size(-1=inf): 50
param 1 12 0    # Logging every (ticks) (e.g. 1, 100): 1
pflags 2b 4 562 424 159 93       #Cells Received: 0
pflags 2a 4      #Cells in VBR Q to link2: 0
pflags 2a 4      #Cells dropped in VBR Q to link2: 0
pflags 2a 4      #Cells in ABR Q to link2: 0
pflags 4b 1 446 547 130 55       #Cells Dropped in ABR Q to link2:
```