The GUI User Manual for the NCTUns 6.0 Network Simulator and Emulator

Authors: **Prof. Shie-Yuan Wang, Chih-Liang Chou, and Chih-Che Lin**

Last update date: January 15, 2010

Produced and maintained by Network and System Laboratory, Department of Computer Science, National Chiao Tung University, Taiwan

Table of Contents

1. Introduction

Welcome to the GUI user manual of NCTUns - a high-fidelity and extensible network simulator and emulator. In this introduction, we will briefly introduce the capabilities and features of NCTUns. To help users understand how NCTUns works, the high-level structure of NCTUns will be presented in detail. Some screenshots are shown in this chapter to let readers get a feel of NCTUns.

Capabilities and Features

NCTUns uses a novel kernel-reentering simulation methodology [1, 2, 3, 4, 5, 6, 7, 8]. As a result, it provides several unique advantages that cannot be easily achieved by traditional network simulators. In the following, we briefly explain its capabilities and features.

High-Fidelity Simulation Results

NCTUns directly uses the real-life Linux's TCP/IP protocol stack to generate high-fidelity simulation results. By using the novel kernel re-entering simulation methodology, a real-life UNIX (e.g., FreeBSD or Linux) kernel's protocol stack is directly used to generate high-fidelity simulation results.

Reusing All Real-Life Application Programs

In NCTUns, all real-life existing or to-be-developed UNIX application programs (e.g., the P2P BitTorrent application) can be run up on a node in a simulated network. This provides several unique advantages: (1) These real-life application programs generate realistic network traffic to drive simulations, which leads to more convincing results than using the artificial traffic generated by some simple "toy" functions, (2) The performances of these real-life applications under various network conditions can be evaluated and then improved before they are released to the public. For example, a network-game application can be first tested, evaluated, and improved on NCTUns before it is released to the public, (3) The applications developed at the simulation study stage can be readily used and deployed on real-life UNIX machines when the simulation study is finished. This will save time and effort significantly.

Same Configuration and Operation as for Real-Life Networks

In NCTUns, the configuration and operation for a simulated network are exactly the same as those for a real-life IP network. This provides two advantages: (1) If a user knows how to configure and operate a real-life IP network, he (she) immediately knows how to configure and operate a simulated network in NCTUns, (2) Conversely, since the configuration and operation of simulated networks in NCTUns are exactly the same as those for real-life IP networks, NCTUns can be used as a training tool to educate people how to configure and operate a real-life IP network. In NCTUns, many valuable real-life UNIX network configuration tools (e.g., route, ifconfig, netstat) and performance monitoring tools (e.g., ping, tcpdump, traceroute) can be directly run on a simulated network to configure and monitor a simulated network.

Seamless Integration of Emulation and Simulation

NCTUns can be turned into an emulator easily. In an emulation, nodes in a simulated network can exchange real packets with real-world machines via the simulated network. That is, the simulated network is seamlessly integrated with the real-life network so that simulated nodes and real-life nodes can exchange their packets across the integrated simulated and real-life networks. This capability is very useful for testing the functions and performances of a real-life device (e.g., a VoIP phone) under various network conditions. In a NCTUns emulation case, an external real-life device can be a fixed host, a mobile host, or a router. NCTUns supports distributed emulation of a large network over multiple machines. If the load of an emulation case is too heavy so that it cannot be carried out in real time on a single machine, this approach can simultaneously use the CPU cycles and main memory of multiple machines to carry out a heavy emulation case in real time. More information about this useful feature is available in a later chapter named "Distributed Emulation."

High Simulation Speeds and Repeatable Simulation Results

NCTUns combines the kernel re-entering simulation methodology with the discrete event simulation methodology. As a result, it executes simulations quickly. NCTUns modifies the process scheduler of the Linux kernel to accurately control the execution order of the simulation engine process and all involved real-life application processes. If the same random number seed is used for a simulation case, the simulation results are repeatable across different runs.

Support for Various Important Networks

NCTUns simulates Ethernet-based IP networks with fixed nodes and point-to-point links. It simulates IEEE 802.11 (a)(b) wireless LAN networks, including both the ad-hoc and infrastructure modes. It simulates GPRS cellular networks. It

simulates optical networks, including traditional circuit switching optical network and more advanced optical burst switching (OBS) networks.

It simulates IEEE 802.11(b) wireless mesh networks, IEEE 802.11(e) QoS networks, tactical and active mobile ad hoc networks, and wireless networks with directional and steerable antennas. It simulates 802.16(d) WiMAX networks, including the PMP and mesh modes. It simulates 802.16(e) mobile WiMAX PMP networks. It simulates 802.16(j) transparent mode and non-transparent mode relay WiMAX networks. It simulates the DVB-RCS satellite networks for a GEO satellite located 36,000 Km above the earth. It simulates 802.11(p)/1609 vehicular networks, which is an amendment to the 802.11-2007 standard for highly mobile environment. Over this platform, one can easily develop and evaluate advanced V2V (vehicle-to-vehicle) and V2I (vehicle-to-infrastructure) applications in the ITS (Intelligent Transportation Systems) research field.

It simulates multi-interface mobile nodes equipped with multiple heterogeneous wireless interfaces. This type of mobile nodes will become common and play an important role in the real life, because they can choose the most cost-effective network to connect to the Internet at any time and at any location.

Support for Various Networking Devices

NCTUns simulates common networking devices such as Ethernet hubs, switches, routers, hosts, IEEE 802.11(b) wireless access points and interfaces, IEEE 802.11(a) wireless access points and interfaces, etc. For optical networks, it simulates optical circuit switches and optical burst switches, WDM optical fibers, and WDM protection rings. For DiffServ QoS networks, it simulates DiffServ boundary and interior routers for QoS provision. For GPRS networks, it simulates GPRS phones, GPRS base stations, SGSN, and GGSN devices. For 802.16(d) WiMAX networks, it simulates the PMP-mode base stations (BS) and Subscriber Stations (SS) and the mesh-mode base stations and Subscriber Stations (SS). For 802.16(e) WiMAX networks, it simulates the PMP-mode base stations (BS) and Subscriber Stations (SS). For 802.16(j) transparent mode and non-transparent mode WiMAX networks, it simulates the base stations (BS), relay stations (RS), and mobile stations (MS). For DVB-RCS network, it simulates the GEO satellite, Network Control Center (NCC), Return Channel Satellite Terminal (RCST), feeder, service provider, traffic gateway. For wireless vehicular networks, it simulates ITS cars each equipped with an 802.11(b) ad hoc-mode wireless interface, ITS cars each equipped with an 802.11(b) infra-structure mode wireless interface, ITS cars each equipped with a GPRS wireless interface, ITS cars each equipped with a DVB-RCST wireless interface, ITS cars each equipped with a 802.16(e) interface, ITS On-Board Unit (OBU) each equipped with a 802.11(p) interface, and ITS cars each equipped with all of these six different wireless interfaces. For mobile nodes each equipped with multiple heterogeneous wireless interfaces, it simulates (1) a traditional mobile node that moves on a pre-specified path (e.g., random waypoints), and (2) an ITS car that automatically move (auto-pilot) on a constructed road.

NCTUns provides more realistic wireless physical modules that consider the used modulation scheme, the used encoding/decoding schemes, the received power level, the noise power level, the fading effects, and the derived BER (Bit Error Rate) for 802.11(a), 802.11(b), 802.11(p), GPRS, 802.16(d) fixed WiMAX, 802.16(e) mobile WiMAX, 802.16(j) relay WiMAX, and DVB-RCST satellite networks. These advanced physical-layer modules can generate more realistic results but at the cost of more CPU time required to finish a simulation. Depending on the tradeoff of simulation speed vs. result accuracy, a user can choose whether to use the basic simple physical-layer modules or the advanced physical-layer modules.

NCTUns supports omnidirectional and steerable antennas with realistic antenna gain patterns. The antenna gain data are stored in a table file and the content of the file can be changed (even time-varying) easily if he (she) would like to use his/her own antenna gain patterns.

Support for Various Network Protocols

NCTUns simulates various protocols such as IEEE 802.3 CSMA/CD MAC, IEEE 802.11 (a)(b)(e)(p) CSMA/CA MAC, the learning bridge protocol used by switches, the spanning tree protocol used by switches, IP, Mobile IP, RIP, OSPF, UDP, TCP, HTTP, FTP, Telnet, etc. It simulates the DiffServ QoS protocol suite, the optical light-path setup protocol, the RTP/RTCP/SDP protocol suite. It simulates the IEEE 802.16(d)(e)(j) WiMAX PMP protocol suites and the 802.16(d) mesh mode protocol suite. It simulates the DVB-RCST protocol suite.

Highly-Integrated and Professional GUI Environment

NCTUns provides a highly-integrated and professional GUI environment in which a user can easily conduct network simulations. The NCTUns GUI program is capable of:

- Drawing network topologies
- Configuring the protocol modules used inside a node

- Configuring the parameter values used inside a protocol module
- Specifying the initial locations and moving paths of mobile nodes
- Plotting network performance graphs
- Playing back the animation of a logged packet transfer trace
- Pasting a map graph on the background of the network topology
- Constructing a road network for wireless vehicular network simulations
- More ...

Popular Operating System Support

NCTUns runs on Linux operating systems. The Linux distribution that NCTUns 6.0 currently supports is Red-Hat Fedora 11, whose Linux kernel version currently is 2.6.28.9. Other Linux distributions such as Debian can also be supported with some minor operating system configuration changes.

Open-System Architecture

By using a set of well-defined module APIs that are provided by the simulation engine, a protocol module developer can easily implement his (her) own protocol and integrate it into the simulation engine. Details about adding a new protocol module to the simulation engine are presented in the "The Protocol Developer Manual for the NCTUns 6.0 Network Simulator and Emulator."

Distributed Architecture for Remote and Concurrent Simulations

By using a distributed architecture, each component of NCTUns can be run on a separate machine. (This is called the "multi-machine" mode.) As such, the machine that runs the GUI program can be different from the machine that runs the simulation engine. This capability sometimes can have an advantage; When simulating a very large case with hundreds of mobile nodes, the GUI will consume many CPU cycles to draw the movements of these mobile nodes during the simulation. However, this will leave few CPU cycles for the simulation engine to simulate the network protocols. To overcome this performance problem, using the multi-machine mode to run the GUI program and the simulation engine on two different machines is a good solution.

In addition, with the job dispatcher program, multiple simulation engine machines can be managed by a single job dispatcher. This architecture design can easily support remote and concurrent simulations, which increases the total simulation throughput when multiple machines are available. Because the components of NCTUns use Inter-Process Communication (IPC, that is, sockets) to communicate, they can also be run on the same machine. (This is called the "single-machine" mode.). In fact, because most people have only one computer to run their simulations, the "single-machine" mode is the default mode after the NCTUns package is installed. Switching between these two modes is very easy and requires changing only one configuration option in a file.

Components and Architecture of NCTUns

NCTUns adopts a distributed architecture. It is a system comprising eight components.

1. The first component is the GUI program by which a user edits a network topology, configures the protocol modules used inside a network node, specifies mobile nodes' initial location and moving paths, plots performance graphs, plays back the animation of a packet transfer trace, etc.
2. The second component is the simulation engine program, which provides basic and useful simulation services (e.g., event scheduling, timer management, and packet manipulation, etc.) to protocol modules. We call a machine on which a simulation engine program resides a "simulation server."
3. The third component is the set of various protocol modules, each of which implements a specific protocol or function (e.g., packet scheduling or buffer management). All protocol modules are C++ classes and are compiled and linked with the simulation engine program.
4. The fourth component is the simulation job dispatcher program that can simultaneously manage and use multiple simulation servers to increase the aggregate simulation throughput. It can be run on a separate machine or on a simulation server.
5. The fifth component is the coordinator program. On every simulation server, the "coordinator" program must be run up. The coordinator should be alive as long as the simulation server is alive. When a simulation server is powered on and brought up, the coordinator must be run up. It will register itself with the dispatcher to join in the dispatcher's simulation server farm. Later on, when the status (idle or busy) of the simulation server changes, it will notify the dispatcher of the new status. This enables the dispatcher to choose an available simulation server from its simulation server farm to service a job.

When the coordinator receives a job from the dispatcher, it forks a simulation engine process to simulate the specified network and protocols. It may also fork several real-life application program processes specified in the job. These processes are used to generate traffic in the simulated network.

When the simulation engine process is alive, the coordinator communicates with the dispatcher and the GUI program on behalf of the simulation engine process. For example, the simulation engine process needs to periodically send its current simulation clock to the GUI program. This is done by first sending the clock information to the coordinator and then asking the coordinator to forward this information to the GUI program. This enables the GUI user to know the progress of the simulation.

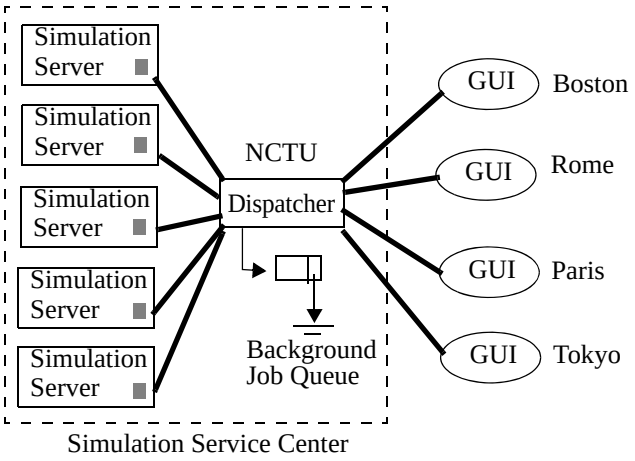
During a simulation, the GUI user can also on-line set or get an object's value (e.g., to query or set a switch's current switch table). Message exchanges that occur between the simulation engine process and the GUI program are all relayed via the coordinator.

6 The sixth component is the kernel patches that need to be made to the kernel source code so that a simulation engine process can run on a UNIX machine correctly. Currently NCTUns 6.0 runs on Red-Hat's Fedora 11, which uses the Linux 2.6.28.9 kernel.

7 The seventh component is the various real-life user-level application programs. Due to the novel kernel-reentering simulation methodology, any real-life existing or to-be-developed application program can be directly run up on a simulated network to generate realistic network traffic.

8 The eighth component is the various user-level daemons that are run up for the whole simulation case. For example, NCTUns provides RIP and OSPF routing daemons. By running these daemons, the routing entries needed for a simulated network can be constructed automatically. As another example, NCTUns provides and automatically runs up several emulation daemons when it is turned into an emulator.

Due to this distributed design, a remote user can submit his (her) simulation job to a job dispatcher, and the dispatcher will then forward the job to an available simulation server for execution. The server will process (simulate) the job and later return the results back to the remote GUI program for further analyses. This scheme can easily support the server farm model in which multiple simulation jobs are performed concurrently on different simulation servers. The following figure shows the distributed architecture of the NCTUns.



The distributed architecture of NCTUns.

In addition to the above "multi-machine" mode, another mode called the "single machine" mode is supported. In such a mode, all of these components are installed and run on a single machine. Although in this mode different simulation jobs cannot be run concurrently on different machines, since most users have only one machine to run their simulations, this mode may be more appropriate for them. In fact, it is the default mode after the NCTUns package is installed.

Some Screenshots of NCTUns

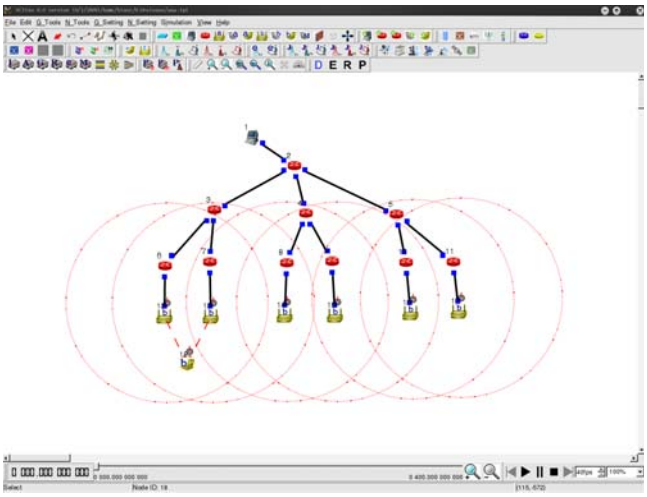
To give readers a quick idea about what the GUI environment looks like, some screenshots of NCTUns are shown below.

Starting Screen

Every time when a user launches the GUI program, the following starting screen will pop up.

Topology Editor

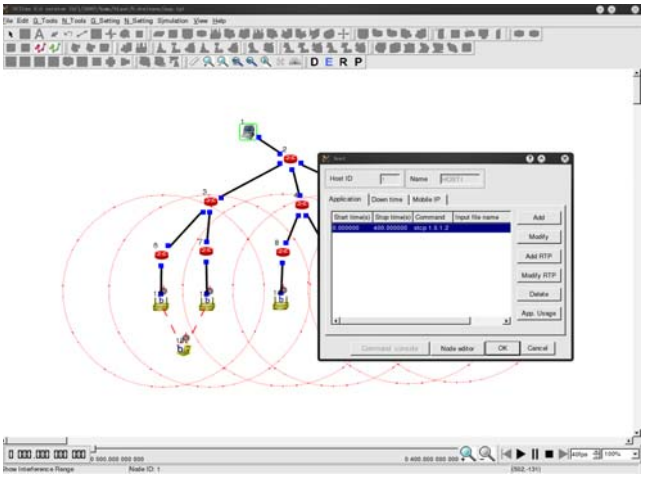
The topology editor provides a convenient and intuitive way to graphically construct a network topology. A constructed network can be a fixed wired network or a mobile wireless network. For ITS applications, a road network can also be constructed. Due to the user-friendly design, all GUI operations can be performed easily and intuitively.



The topology editor of NCTUns

Attribute Dialog Box

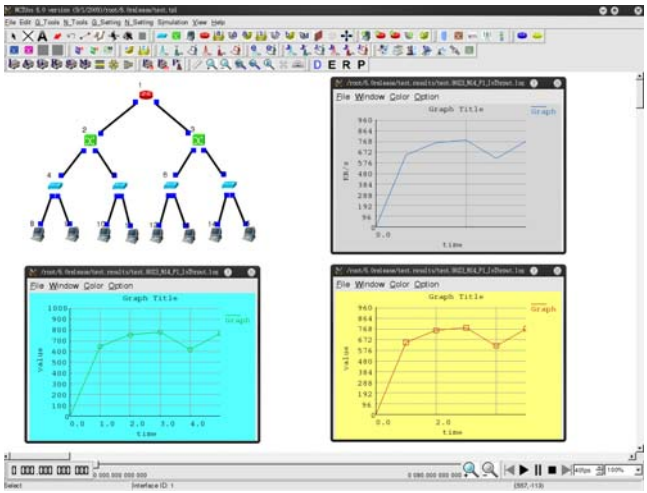
A network device (node) may have many attributes. Setting and modifying the attributes of a network node can be easily done. Just double-clicking the icon of a network node. An attribute dialog box pertaining to this node will pop up. A user can then set the device's attributes in the dialog box.



A popped-up dialog box of NCTUns

Performance Monitor

The performance monitor can easily and graphically generate and display plots of some monitored performance metrics over time. Examples include a link's utilization or a TCP connection's achieved throughput. Because the format of its input data log file uses the general two-column (x, y) format and the data is in plain text, the performance monitor can be used as an independent plotting tool.



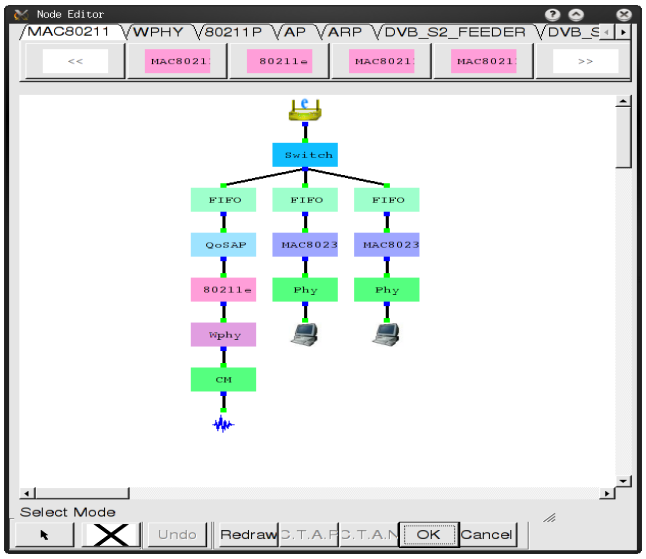
The performance monitor of NCTUns

Node Editor

The node editor provides a convenient environment in which a user can flexibly configure the protocol modules used inside a network node. By using this tool, a user can easily add, delete, or replace a module with his (her) own module. This capability enables a user to easily test the performance of a new protocol.

Using the node editor, a user can also conveniently set the parameter values used by a specific protocol module. Each box in the node editor represents a protocol module. A user can double-click a protocol module box to pop up its parameter dialog box.

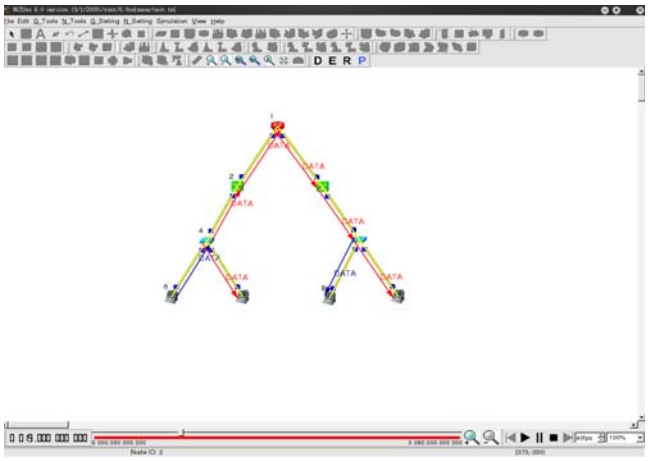
Regarding how to add a new protocol module to the node editor (i.e., to let it know that a user has added a new protocol module to the simulation engine), readers should refer to the "The Protocol Developer Manual for the NCTUns 6.0 Network Simulator and Emulator."



The node editor of NCTUns

Packet Animation Player

By using the packet animation player, a packet transfer trace logged during a simulation can be replayed at a specified speed. Both wired and wireless networks are supported. This capability is very useful because it helps a researcher visually see and debug the behavior of a network protocol. It is very useful for educational purposes because students can see how a protocol behaves.



The packet animation player of NCTUns

Summary

In this chapter, we have briefly presented the features and capabilities of NCTUns. After reading this chapter, readers now should have a high-level view about NCTUns 6.0. In the next chapter, we will present how to install the NCTUns package. To let readers quickly get a feel of the operations of this tool, a short tour about running a simple simulation case will be presented in the next chapter.

Reference

[1] S.Y. Wang and H.T. Kung, “A Simple Methodology for Constructing Extensible and High-Fidelity TCP/IP Network Simulator,” IEEE INFOCOM’99, March 21-25, 1999, New York, USA.

[2] S.Y. Wang and H.T. Kung, “A New Methodology for Easily Constructing Extensible and High-Fidelity TCP/IP Network Simulators,” Computer Networks, Vol. 40, Issue 2, October 2002, pp. 257-278.

[3] S.Y. Wang, “NCTUns 1.0,” in the column “Software Tools for Networking,” IEEE Networks, Vol. 17, No. 4, July 2003.

[4] S.Y. Wang, C.L. Chou, C.H. Huang, C.C. Hwang, Z.M. Yang, C.C. Chiou, and C.C. Lin, “The Design and Implementation of NCTUns 1.0 Network Simulator,” Computer Networks, Vol. 42, Issue 2, June 2003, pp. 175-197.

[5] S.Y. Wang and Y.B. Lin, “NCTUns Network Simulation and Emulation for Wireless Resource Management,” Wireless Communication and Mobile Computing, Wiley, Vol. Issue 8, pp. 899 ~ 916, December 2005.

[6] S.Y. Wang and K.C. Liao, “Innovative Network Emulations using the NCTUns Tool,” as a book chapter of the “Computer Networking and Networks” book, (ISBN 1-59454-830-7, published by Nova Science Publishers)

[7] S.Y. Wang, C.L. Chou, C.C. Lin, “The Design and Implementation of the NCTUns Network Simulation Engine,” Elsevier Simulation Modelling Practice and Theory, 15 (2007) 57 -81.

2. Getting Started

This chapter presents a simple tour to help readers quickly learn how to use NCTUns. First, we give instructions on how to install NCTUns on a single machine. Next, we present step-by-step instructions to illustrate how to quickly run up a simple simulation case.

Installation and Configuration

In the following, we assume that when installing the package, the user uses the package's default settings.

A user first downloads the package from the web site at http://NSL.csie.nctu.edu.tw/nctuns.html. Starting from the 2.0 version, the operating systems that NCTUns supports is only Linux and FreeBSD is no longer supported. Right now, the Linux distribution supported is Red Hat's Fedora 11, which uses Linux kernel version 2.6.28.9.

After reading the installation explanations and instructions (INSTALL, README, FAQ, KNOWN.PROBLEM, RELEASE.NOTE) and running the installation script (install.sh), a directory named "nctuns" will be created in the /usr/local/ directory, which in turn has several subdirectories. The name of these subdirectories are "bin," "etc," "tools," "BMP", and "lib," respectively. In the following, we explain each of these subdirectories briefly.

1. /usr/local/nctuns/bin

This directory stores executable programs of the GUI program, dispatcher, coordinator, and the simulation engine. Their names are "nctunsclient," "dispatcher," "coordinator," and "nctunsse," respectively.

2. /usr/local/nctuns/tools

This directory stores executable programs of various applications and tools pre-installed by NCTUns. For example, currently "stcp," "rtcp," "ttcp," "tcpdump," "ripd," "ospfd," "nctunstcsh," "script," "stg," "rtg," "tsetenv," "ifconfig," and "ping" are supported. Some daemon programs used by NCTUns are also stored in this directory. For example, the daemon programs used for emulation and Mobile IP are stored here. The agent programs that are used for tactical and active mobile ad hoc network simulations (e.g., "Magent1") are also stored here. These tactical agent programs can be run on mobile nodes to control the moving behavior of mobile nodes.

Due to the use of a novel kernel-reentering simulation methodology, NCTUns has two advantages as follows: (1) Any real-life application program can be run on a simulated network to generate traffic and (2) Their performance can be evaluated under different simulated network conditions. Thus the real-life application programs pre-installed in this directory represent only a very small subset of real-life application programs that can be used with NCTUns.

During simulation, if a user wants the simulation engine to run up an application program that is not pre-installed in this subdirectory (e.g., the P2P BitTorrent program), the user must first copy that program into this subdirectory (i.e., /usr/local/nctuns/tools) so that the simulation engine can find it during simulation. Detailed information on how to specify which application programs should be run on which nodes in the GUI program is presented in the "Topology Editor" chapter.

3. /usr/local/nctuns/etc

This directory stores the configuration files needed by the dispatcher and coordinator programs. Their names are "dispatcher.cfg," and "coordinator.cfg," respectively. Some other configuration files used by NCTUns are also stored here. For example, the "app.xml," which is read by the GUI program to explain the usages of pre-installed application programs, is also stored here. An "mdf" subdirectory (which stands for "module definition file") is created here. Inside this directory, the parameter definitions and dialog box layout design of supported protocol modules are stored in separate subdirectories. The GUI program will read the files inside the mdf directory to know the definition of supported protocol modules. The "ps.cfg" file describes the default internal protocol stack used by each supported network node.

4. /usr/local/nctuns/BMP

This directory stores the icon bmp files used by the GUI program. These icon files are used for displaying various devices' icons and control buttons.

5. /usr/local/nctuns/lib

This directory stores the libraries used by the simulation engine. For example, the more advanced signal propagation model library used by IEEE 802.11(b) advanced wireless physical module is installed here. NCTUns supports RTP/RTCP/SDP protocols and implements some of their functions as a library that can be called by RTP/RTCP/SDP application programs.

Installation Procedure

Before starting the installation, a user should first carefully read the “README” and “INSTALL” files. Both of these files contain important installation information. The RELEASE.NOTE file contains notes relevant to each release of NCTUns. These notes point out the new functions, bug fixes, performance and GUI improvements, data structure and program changes, etc. between the current and the previous releases. The FAQ file answers technical questions that may result due to an incorrect installation. The KNOWN.PROBLEM file lists some known system problems. For example, if a computer is equipped with a very new video card, the new video card driver may not work well with Fedora 11.

A user then runs the “install.sh” shell script. This script will install the pre-compiled Linux kernel image patched for NCTUns. It will also build all executable programs and copy them to their default subdirectories. In addition, it will create 4,096 (this number can be easily increased) tunnel special files (tunnel interfaces) in /dev. These steps may take some time.

During the installation, the user should carefully watch out whether some error messages are generated. If any serious error message is generated, the installation may fail.

After the installation is successfully finished, the machine must be rebooted and then the user must choose the NCTUns kernel to boot. After the machine boots up with the NCTUns kernel, the whole installation can be considered successful.

Before start running NCTUns to conduct simulations, the user should carefully read the FINALCHECK file. This file lists the important operations that the user must have performed to run NCTUns correctly. According to our technical service experiences, almost every reported problem is caused by not performing all of these required operations.

More detailed and up-to-date installation and usage information can be found in the NCTUns package.

A Quick Tour

Setting up the environment

Suppose that a user uses the single-machine mode of NCTUns, before he (she) starts the GUI program, he (she) must perform three operations.

1. Set up environment variables

Before a user can run up the dispatcher, the coordinator, and the GUI programs, he (she) must first set up the NCTUNSHOME environment variable. To do so, a user can type in and execute the “setenv NCTUNSHOME /usr/local/nctuns/” shell command in his (her) terminal window (i.e., xterm) if the csh or tcsh shell is used. For the bash shell, the command should be “export NCTUNSHOME=/usr/local/nctuns.” Two other environment variables must be set as well. The first is NCTUNS _TOOLS and the second is NCTUNS_BIN. They must be set to /usr/local/nctuns/tools and /usr/local/nctuns/bin, respectively.

For a user’s convenience, the installation script will place the nctuns.csh and nctuns.bash file in /usr/local/nctuns/etc when the installation is completed. The user can use the command “source /usr/local/nctuns/etc/nctuns.csh” to set these environment variables if his (her) shell is csh or tcsh. Similarly, if the user uses bash, he (she) can use the command “source /usr/local/nctuns/etc/nctuns.bash” to set these environment variables.

2. Start up the dispatcher

Now a user can run up the dispatcher, which is located in /usr/local/nctuns/bin. Note that the user must be the root user to run dispatcher correctly.

The default port number used by the dispatcher to receive messages sent from the coordinator program(s) is 9,810. It is 9,800 for the dispatcher to receive messages sent from the GUI program(s). These default settings can be found and changed in the dispatcher.cfg file, which is located in /usr/local/nctuns/etc/.

3. Start up the coordinator

Now the user can run up the coordinator, which is located in /usr/local/nctuns/bin. Note that the user must be the root user to run coordinator correctly.

Since the coordinator needs to register itself with the dispatcher, we must let the coordinator know the port used by the dispatcher to receive the registration messages. (It is 9,810 in the above example.) This port information is specified and can be changed in the coordinator.cfg file located in /usr/local/nctuns/etc/.

The second important information that the coordinator must know is the IP address used by the dispatcher. If the user is using the single-machine mode, since the dispatcher and the coordinator are run on the same machine, the IP address can be specified as 127.0.0.1, which is the default IP address assigned to the lo loopback network interface. In case the 127.0.0.1 IP address cannot work due to some unexpected

reasons, the user can replace it with the machine's own IP address (e.g., 140.113.17.5). This setting should always work.

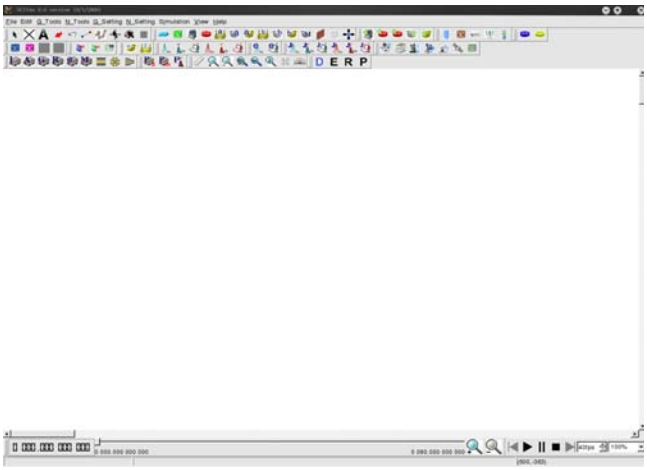
If a user is using the multi-machine mode and the dispatcher is running on a remote machine, the IP address specified should be the IP address of that remote machine.

4. Start up the nctunsclient

After all of the above steps are performed, a user can now launch NCTUns's GUI program (called nctunsclient). This program is also located in /usr/local/nctuns/bin. To run the GUI program successfully, the user need not be the root user.

Draw a Network Topology

After the starting screen of NCTUns disappears, a user will be presented a working window shown below.



The working area of the topology editor

To edit a new network topology, a user can perform the following steps.

1. Choose **Menu->File->Operating Mode** and make sure that the "Draw Topology" mode is checked. Actually, this is the default mode which NCTUns will be in when it is launched.

It is important to note that only in the "Draw Topology" mode can a user draw a new network topology or change an existing simulation case's topology. When a user switches the mode to the next mode "Edit Property," the simulation case's network topology can no longer be changed. Instead, only devices' properties (attributes) can be changed at this time.

The GUI program enforces this rule because when the mode is switched to the "Edit Property" mode, for the user's convenience, the GUI program will automatically generate many settings (e.g., a layer-3 interface's IP and MAC addresses). Since the correctness of these settings depends on the current network topology, if the network topology gets changed, these settings may become incorrect.

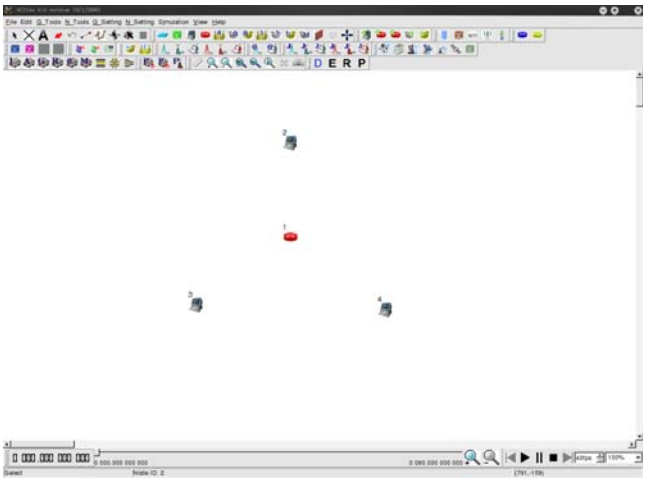
If after editing some devices' properties, the user would like to change the network topology, he (she) will need to explicitly switch the mode back to the "Draw Topology" mode. However, when the mode is switched from the "Draw Topology" mode back to the "Edit Property" mode again, many settings that were automatically generated by the GUI program will be re-generated automatically by the GUI program to ensure their correctness.

For example, the IP and MAC addresses automatically assigned to a layer-3 network interface may have been changed. The user thus better re-checks the settings for application programs (traffic generator) that he (she) specified when he (she) was in the "Edit Property" mode. This is because these application programs now may use wrong IP addresses to communicate with their intended partners.

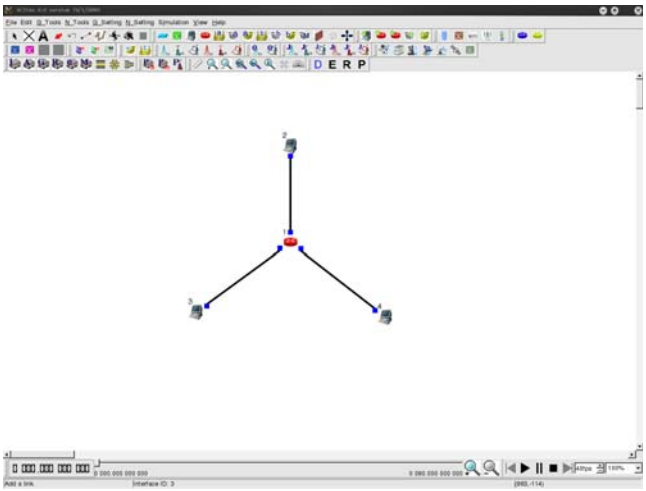
2. Move the mouse cursor to the tool bar, which is shown below.

3. Left-click the router icon ( ) on the toolbar.
4. Left-click somewhere in the blank working area to add a router to the current network topology (which is empty now).
5. Left-click the host icon ( ) on the toolbar.

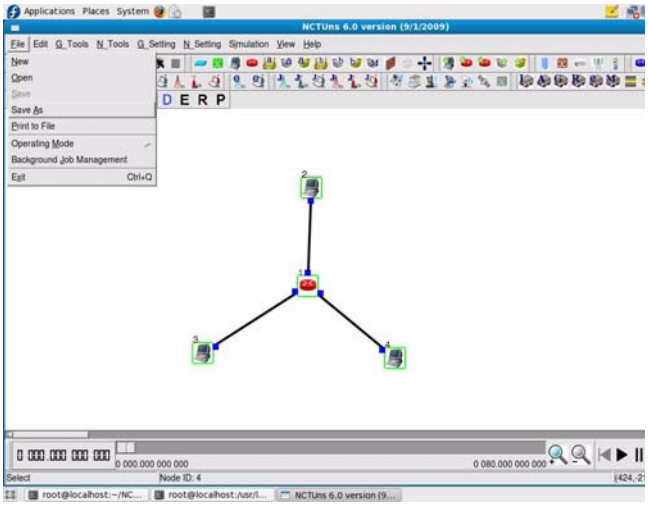
Like in step 4, add three hosts to the current network topology. The resulting topology is shown below.



6. Now we want to add links between the hosts and the router. Left-click the link icon ( ) on the toolbar to select it.
7. Left -click a host and hold the mouse button. Drag this link to the router and then release the mouse left button on top of the router. Now a link between the selected host and the router has been created.
8. Add the other two links in the same way. Now the simple network topology has been created.



9. Remember to save this network topology by choosing **Menu** -> **File** -> **Save As**. For this simple case, we will save the topology file as "test.tpl." When the GUI program creates test.tpl, it also creates test.xtpl. This file stores the attribute values stored in test.tpl in an XTML-like text format. This allows a user to easily view and check the stored attribute values.



It is not mandatory to save the network topology into a file in this mode. A user can save it in the "Edit Property" mode. Depending on in which mode a network topology file was saved, when the file is opened again, its current mode will be automatically set to the mode when it was saved.

Editing Nodes' Properties

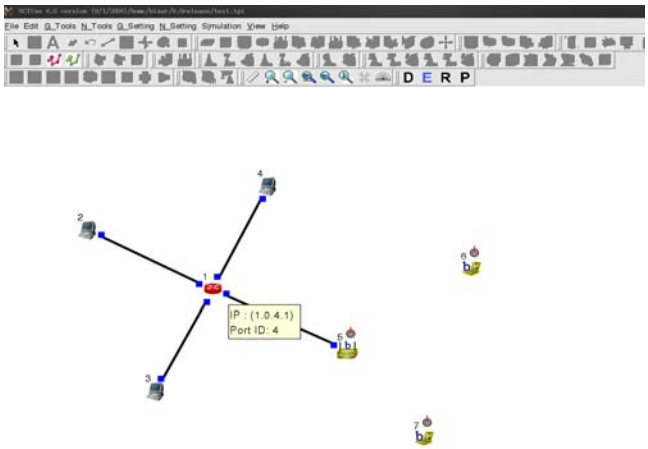
A network node (device) may have many parameters to set. For example, we may want to set the maximum queue length of a FIFO queue used inside a network interface. For another example, we may want to specify that some application programs (traffic generators) should be run up on some hosts or routers to generate network traffic.

Before a user can start editing the properties of network nodes, he (she) should switch the mode from the "Draw Topology" to the "Edit Property" mode. In this mode, topology changes can no longer be made. That is, a user cannot add or delete network nodes or links at this time. If the user has not given a name to this simulation case, the GUI program will pop up a dialog box at this time asking the user to specify one.

To save the user's configuration time, the GUI program automatically finds subnets in a fixed network, and generates and assigns IP and MAC addresses to all layer-3 network interfaces. In addition, the GUI program automatically generates and assigns MAC addresses to layer-2 network interfaces. Note that layer-3 interfaces are used by layer-3

devices such as hosts, routers, and mobile nodes, and layer-2 interfaces are used by layer-2 devices such as switches and wireless LAN access points.

The generated IP addresses use the 1.0.subnetID.hostNumOnThisSubnet format, where subnetID and hostNumOnThisSubnet are automatically assigned. The IP and MAC addresses generated and assigned to an interface can be known easily. When a user moves the mouse cursor onto a blue box, which represents a network interface, the IP address assigned to it along with the port ID assigned to it will be shown. The following figure shows an example.

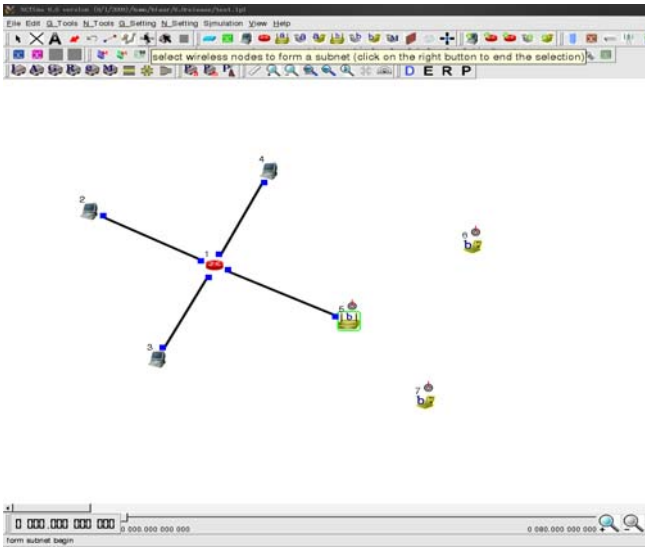


Due to this address format, NCTUns allows a simulation case to have up to 254 subnets (subnet ID 0 and 255 are excluded because they are used for broadcast purposes), each of which can have up to 254 nodes (hostNum 0 and 255 are excluded because they are used for broadcast purposes). That is, in total a maximum number of 254 * 254 = 64,516 layer-3 interfaces can be supported in a simulation case.

Although in theory NCTUns can support this large number of layer-3 interfaces in a simulation case, in practice this is rarely done. This is because each layer-3 interface needs to be simulated by a tunnel network interface but currently the installation script creates only 4,096 tunnel interfaces on a UNIX machine by default. So, precisely speaking, currently NCTUns can support a simulation case using up to 4,096 layer-3 interfaces. This also means that currently the maximum number of mobile nodes in a mobile ad-hoc network simulation case cannot exceed 4,096. (This is because each mobile node uses a layer-3 interface.) This limitation can be easily raised to a larger number such as 8,192 by creating more tunnel interfaces on the simulation machine. This change can be easily done by modifying the installation script.

The used subnet number starts from 1 and automatically grows upward. The used host number on a subnet also starts from 1 and automatically grows upward. If there are WLAN ad-hoc mode mobile nodes in the network, the subnet ID 1 is reserved and used for the ad-hoc subnet formed by these ad-hoc mode mobile nodes. In such a case, the subnet number used for fixed subnets will start from 2. On the other hand, if there is no ad-hoc mode mobile node in the network, the subnet number used for fixed subnets will start from 1.

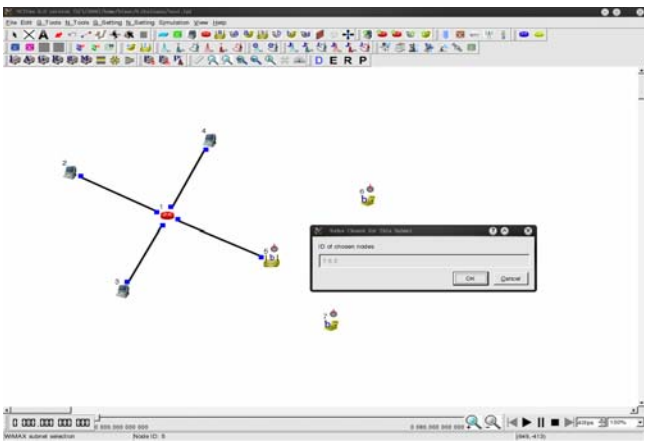
The GUI program can automatically generate and assign IP addresses to ad-hoc mode mobile nodes (or), hosts, and routers on the fixed network. For infrastructure mode mobile nodes (or), however, the GUI program needs helps from the “form subnet” ( ) tool to automatically generate and assign IP addresses to them. The full name and location of this tool are shown in the following figure. More information on the usage of this tool will be presented in a later chapter.



The reason is that an infrastructure mode mobile node needs to use an access point to connect itself to the fixed network. To successfully send and receive packets to and from the fixed network, the infrastructure mode mobile node needs to use an IP address whose subnet ID is the ID of the subnet that the access point belongs to. However, during the automatic IP address generation process, the GUI program does not have the intelligence to know which subnet the user would like an infrastructure mode mobile node to belong to (e.g.,

suppose that there are two access points each of which belongs to a different subnet). As a result, without the subnet relationship information, the GUI program cannot intelligently generate and assign an appropriate IP address to an infrastructure mode mobile node.

To help the GUI program solve this problem, the user needs to manually select the involved infrastructure mode mobile nodes and the desired wireless access point to form a wireless subnet. With this subnet grouping information, the GUI program now knows the access point with which these infrastructure mode mobile nodes would like to associate. As a result, it knows the subnet ID that should be assigned to this wireless subnet and it can assign a unique and correct IP address to each of these infrastructure mode mobile nodes automatically. With this design, the user need not configure the gateway IP address for these infrastructure mode mobile nodes. The GUI program intelligently knows this information by tracking the access point back to the router that has a network interface connecting to this access point. The IP address of this network interface is the gateway IP address for these infrastructure mode mobile nodes. The following figure shows that the "form subnet" tool is used to select two infrastructure mode mobile nodes and one access point to form a wireless subnet.



A user must be aware that if he (she) switches the mode back to the "Draw Topology" mode, when he (she) again switches the mode back to the "Edit Property" mode, nodes' IP and MAC addresses will be re-generated and assigned to layer-3 interfaces. Therefore the application programs (traffic generator) now may use wrong IP addresses to communicate with their partners.

In this mode, since the IP and MAC addresses and the port ID of an interface have been automatically generated and assigned, the GUI will automatically show these information when a user moves the mouse cursor and place it over the blue interface box on the screen for a while. This can conveniently let the user see the results of these assignments.

In addition to automatically generating IP and MAC addresses, the GUI program also automatically and silently performs many tasks for the user. Many of these tasks are performed underground to automatically correct a user's configuration mistakes. This is to avoid generating wrong simulation results and causing simulation crashes.

For example, the GUI program will automatically set the promiscuous mode of the 802.3 MAC modules that are used inside a switch to ON, no matter how the user set them. (The promiscuous mode is defaulted to OFF because the 802.3 MAC modules used inside hosts and routers need to filter out unwanted frames.) This ensures that frames can be forwarded by the switch without any problem. Otherwise, if the promiscuous mode is not turned ON, frames will be discarded by the switch's 802.3 MAC modules.

Another task that the GUI program does for the user is to ensure that all interfaces that connect to a hub uses the hub's bandwidth as their interface bandwidth and the operating mode of the 802.3 MAC modules in these interfaces all be set to "half-duplex." In the GUI program, a user can independently set different bandwidths for different interfaces and set an 802.3 MAC module's mode to either "full-duplex" or "half-duplex" without considering whether these interfaces are connected to a hub. These wrong configurations surely will generate wrong simulation results and may even cause a simulation to crash. This kind of wrong configuration bug is difficult to detect for a careless user. As a result, the GUI program does several underground tasks to save the user's debugging time and increase his (her) productivity.

Yet another task that is automatically done by the GUI program is that the GUI program will force the switch module used inside an access point (

or 

) to use the "Run_Learning_Bridge" mode, despite the fact that the user may configure it to use the "Build in Advance." These two modes affect how the switch forwarding table used inside the switch module is built. The first method is a dynamic method while the second is a static one. The second method works very well for fixed networks. However, in mobile networks where mobile nodes move around and change their associated access points constantly, the static method will no longer work correctly. To prevent the user from suffering unexpected (wrong) simulation behavior and results, the GUI program automatically forces the switch module used

inside all access points to use the “Run_Learning_Bridge” method to dynamically build and update their forwarding tables.

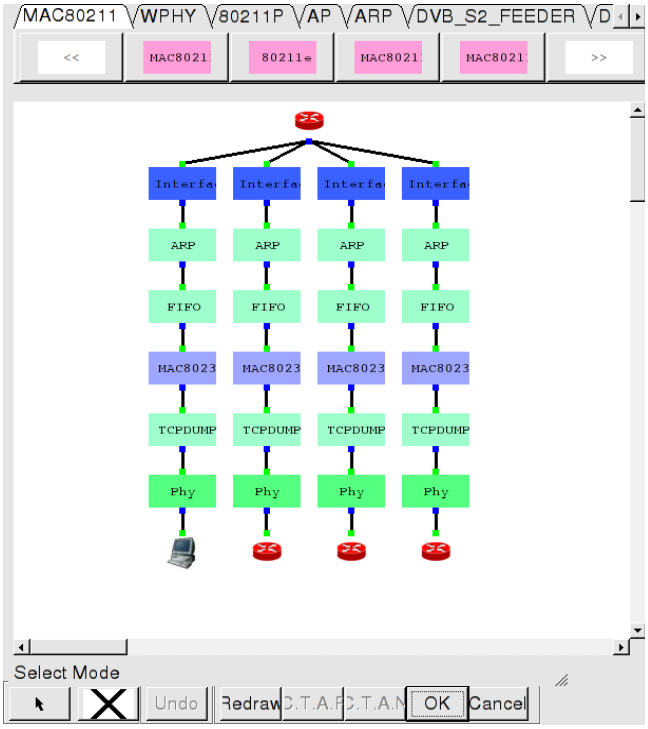
Therefore, in the future when you see that the GUI program does not honor your settings for some devices or protocol modules, do not be surprised. You know that the GUI program is doing this for your good.

Editing network nodes’ properties can be done in two steps. In the first step, a user can use the mouse to double-click a node’s icon. A dialog box will appear in which a user can set parameter values or option values. The following figure shows an example dialog box after the user double-clicks the router icon.

The router’s dialog box

In the second step, a user can use the node editor to specify the protocol module parameters used inside a network node. To enter the node editor, a user first double-clicks the node’s icon to pop up its dialog box. Then the user double-clicks the “node editor” button in the dialog box. The following figure shows the popped node editor and the protocol modules used inside the router.

One important task in the “Edit Property” mode is to specify which application programs (traffic generators) should run on which nodes during simulation to generate network traffic. Application programs can run on hosts, routers, mobile nodes (including both the ad-hoc and infra-structure modes), GPRS phones, IEEE 802.16(d) WiMAX BS and SS, IEEE 802.16(e) mobile WiMAX BS and MS, IEEE 802.16(j) relay WiMAX BS, RS, and MS, DVB-RCST, ITS



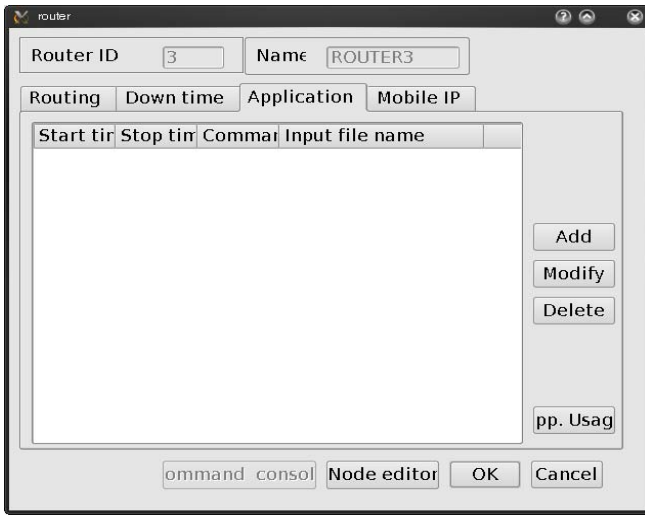
The popped-up node editor for the router node

cars, multi-interface nodes, 802.11(p) OBU and RSU, etc. Actually, as long as a node has a layer-3 interface (which should have an IP address assigned to it), any application program can run on it. In such devices’ dialog boxes, there is an “Application” tab in which a user can specify the commands for launching the desired application programs.

For example, suppose that a user wants to sets up a greedy TCP connection between two nodes. He (she) can specify the command “rtcp -p 8000” on the receiving node’s Application tab and specify the command “stcp -p 8000 1.0.1.2” on the sending node’s Application tab. In this case, stcp and rtcp are the pre-installed real-life application programs that will greedily send and receive TCP data, respectively. Also, we assume that the receiving node has an assigned IP address of 1.0.1.2 and the rtcp program binds its receiving socket to port 8000.

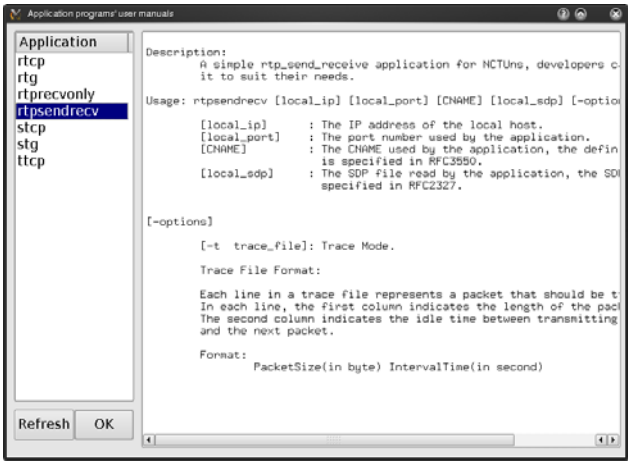
From the above example, one sees that the specified commands are exactly the same as what a user would type into a UNIX terminal to launch (run up) these application programs.

The “App. Usage” button in the following dialog box provides command usage information for each pre-installed application program. When a GUI user double-clicks this button, a program usage information window will pop up showing the detailed usage for each pre-installed application



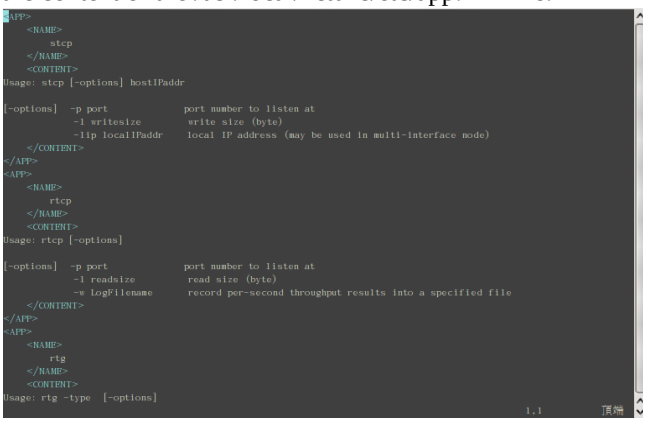
In the application tab a user can specify which application programs should be run up on this node.

program. The following figure shows the content of this window. For the first use, the user needs to click the "Refresh" button to get the latest program usage information from the (may be local or remote) dispatcher.



The content of the program usage information window.

If a GUI user wants to install a new application program, he (she) needs to copy that program into the /usr/local/nctuns/tools directory so that the simulation engine can successfully find and execute it. If the GUI user also wants the usage information of this new program to be displayed in the above program usage window, he (she) needs to edit the /usr/local/nctuns/etc/app.xml file and put the program's usage information into that file. The format of this file is easy to understand. The following figure shows the content of the /usr/local/nctuns/etc/app.xml file.



The content of the program usage information file (app.xml).

Running the simulation

When a user finishes editing the properties of network nodes and specifying application programs to be executed during a simulation, he (she) can start to run the simulation. To do so, the user must switch the mode explicitly from "Edit Property" to "Run Simulation." Entering this mode indicates that no more changes can (should) be made to the simulation case, which is reasonable. The simulation is about to be started. At this moment, of course, no settings should be changed.

When the mode is switched to the "Run Simulation" mode, the GUI will export many simulation files that collectively describe the simulation case. These simulation files will be transferred to the (either remote or local) simulation server for it to execute the simulation. These files are stored in the "mainFileName.sim" directory, where mainFileName is the name of this simulation case.

For example, suppose that the topology file is named "test.tpl," these exported simulation files will be stored in a directory named "test.sim." Among these exported files, the test.tcl file stores the configuration of each node's protocol stack and the network topology information. This file is very important and should always go with the test.tpl and test.xtpl files. Therefore, if a user wants to move (or copy) a simulation case from one place to another place in a file system, he (she) must move (or copy) the .tpl and .xtpl files and their associated .sim directory at the same time. Otherwise, the moved (or copied) simulation case cannot be successfully reloaded. For this particular example, he (she) must move test.tpl, test.xtpl, and test.sim/ at the same time.

In addition to the ".sim" directory, a directory named "mainFileName.results" is also created. This directory will store the generated simulation results when they are transferred back to the GUI program after the simulation is finished.

It is important to note that before a user runs a simulation case, he (she) can still switch the mode back to the "Edit Topology" or even the "Draw Topology" mode to change any setting of the simulation case. However, when the mode is switched back to the "Run Simulation" mode, all simulation files will be re-exported to reflect the most recent settings.

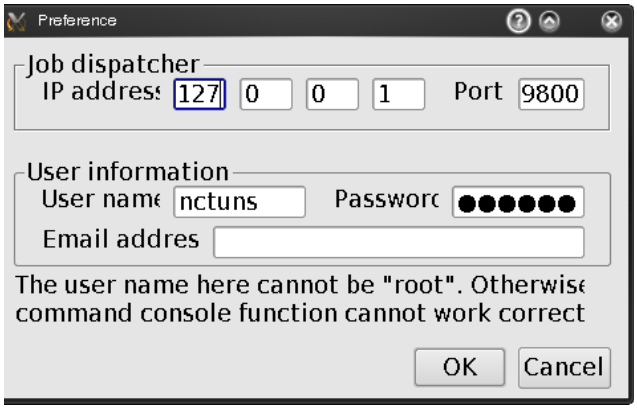
Before a user runs a simulation, he (she) must make sure that the dispatcher and coordinator are already running. Suppose that the user uses the single-machine mode of NCTUns, he (she) needs to run up the dispatcher and coordinator programs first. The following procedure assumes that the user uses the single-machine mode. If the user uses a simulation service center (running in the multi-machine mode) that is already set up by some person or institute, he (she) can skip the following two steps.

1. Run the "dispatcher" program located in /usr/local/nctuns/bin. The default values of the parameters needed by this program is stored in /usr/local/nctuns/etc/dispatcher.cfg.
2. Run the "coordinator" program located in /usr/local/nctuns/bin. The default values of the parameters needed by this program is stored in /usr/local/nctuns/etc/coordinator.cfg.

Now the user needs to let the GUI program know the IP address and port number used by the dispatcher. The user should configure these settings by invoking the **Menu -> G_Setting -> Dispatcher** command. The following figure shows the popped-up dialog box.

The default port number is 9,800. If the user is using the single-machine mode, the IP address can be specified as 127.0.0.1, which is the default IP address that the UNIX system automatically assigns to the loopback interface. The user name and password must be valid. For the single-machine mode, it is the user's account on this local machine. For the multi-machine mode, it is the user's account on the chosen remote simulation machine.

Note that in the multi-machine mode, because simulations are actually performed on a simulation server machine, the user must also have the same account on any simulation server machine that is managed by the dispatcher. To guarantee this property, normally a simulation service center will use NFS (network file system) and YP password facilities. This will make sure that all machines in this service center share the same user account database and share the same file system.



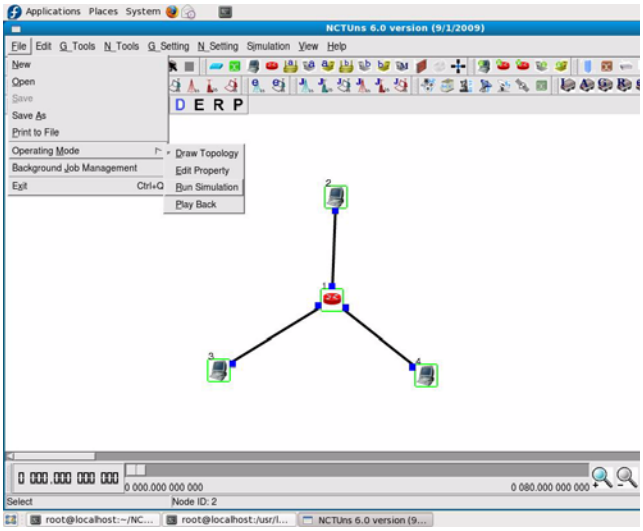
The popped-up dialog box for setting dispatcher-related information.

The user name specified in this dialog box cannot be "root." That is, the GUI user should not use the root account to log onto a simulation server, no matter whether it is a local or remote machine. This enforcement is for security concerns. Also, if the GUI user logs on a simulation server as the "root" user, he (she) will not be able to use the command console function correctly. For these reasons, the "root" account is blocked here by the GUI program.

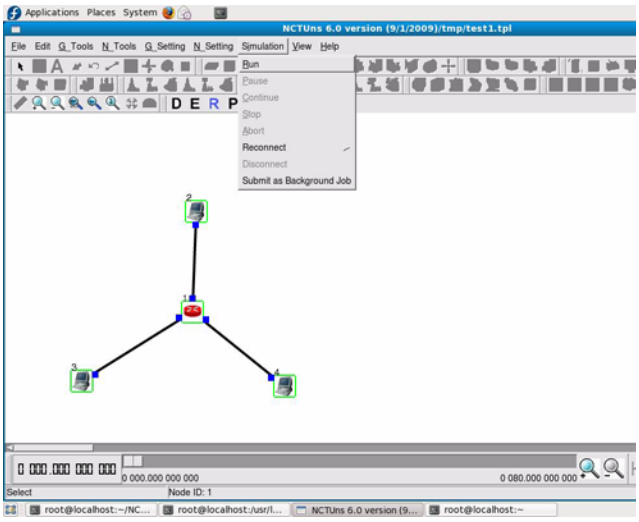
During simulation (i.e., when the simulation is not finished yet), the result files generated by the simulation engine are stored in a working directory inside the home directory of the provided user account. Hence, this user account information must be correct and valid. Otherwise, the GUI program will crash due to access permission errors. Specifying the email address is not mandatory. However, if this information is provided, a remote dispatcher can send back a notification email to the user when the user's background job is finished in its simulation service center. Currently, this notification function is not implemented.

Since we have specified a complete simulation case and we are certain that the dispatcher and coordinator programs are running, we can now proceed to run the simulation.

3. Choose **Menu -> File -> Operating Mode** and select "Run Simulation".



4. Choose **Menu -> Simulation -> Run**. Executing this command will submit the current simulation job to one available simulation server (or the only local simulation server) managed by the dispatcher.



5. When the simulation server is executing, the user will see the time knot at the bottom of the screen move. The time knot reflects the current simulation time (progress) of the simulation case. Currently, the maximum time that can be simulated for a simulation case is set to 4,200 seconds.

Playing Back the Packet Animation Trace

After the simulation is finished, the simulation server will send back the simulation result files to the GUI program. After receiving these files, the GUI program will store these files in the ".results" directory. It will then automatically switch to the "Play Back" mode.

To save the network bandwidth and time required for transferring these huge files across a network, these result files are tarred (using the tar command) and gzipped (using the gzip command) into a tar ball before being sent to the GUI program. This usually can reduce the bandwidth usage by a factor of 10 or above. After receiving the tar ball, the GUI program needs to untar and ungzip the tar ball before using these files. As a result, a user may experience some delay up to a few minutes (depending on the machine's speed) without any progress update on the screen. At this moment, the user needs to be patient.

These files include a packet animation trace file and all performance log files that the user specified to generate. Generating these performance log files can be specified by checking some output options in some protocol modules (e.g., 802.3 or 802.11(b) protocol modules) in the node editor. In addition, application programs can generate their own data log files. For example, the pre-installed "rtg" program can be specified to output a performance log file showing the end-to-end delays experienced by all received packets.

The packet animation trace file can be replayed later by the packet animation player. The performance curve of these log files can be plotted by the performance monitor. Details about the animation player and the performance monitor will be explained in later chapters.

For this simple case, the packet animation trace file is named "test.ptr," which uses the main file name of the topology file -- "test.tpl." The .ptr file is a logged packet transfer trace file. Its animation can be played by the animation player at a specified speed. To save disk space and transfer time, the .ptr is a binary file, which means that its content cannot be directly viewed using a normal text editor such as vi or emacs. To allow a user to convert it into a text file for inspection, a "printPtr" utility program is provided in /usr/local/nctuns/bin. In addition, the user can also execute the GUI's **Menu -> G_Tools -> View Packet Trace** command to view a simulation case's .ptr file.

When the GUI program has untarred and ungzipped the .ptr file, it will automatically switch to the "Play Back" mode. In this mode, the control buttons of the time bar located at the bottom of the screen can be used to play, stop, pause, continue, jump forward, jump backward, or "intelligently" jump forward the animation.

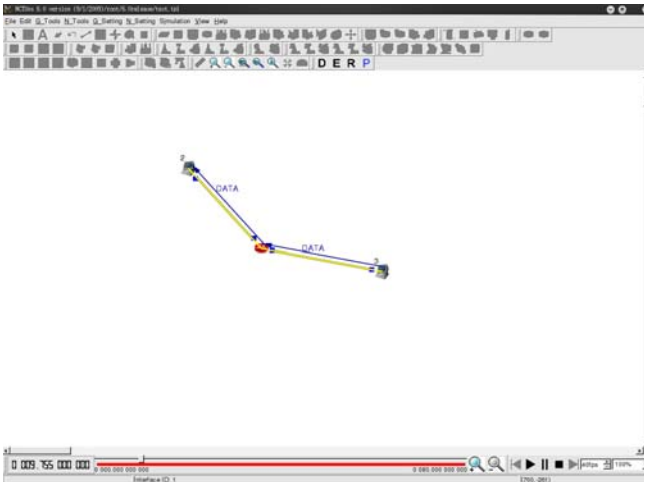
The user can also use the mouse to directly move the time knot to any desired time to see the packet transfers occurring at that moment. To precisely move the time knot to a specific

time, the user can even double-click the time-display (i.e., the LCD clock display) area to pop up a window. In this window, the user can directly enter the desired time in ticks. For example, if the user wants to see the packet transfers occurring at 1.2345678 seconds, then he (she) can enter 12345678 into this window. The default mapping between 1 tick and its corresponding time duration in simulation time is 1 tick -> 100 nanoseconds. This mapping can be changed by **Menu->G_Setting->Simulation->Speed** for high-speed networks such as 1 Gbps optical networks.

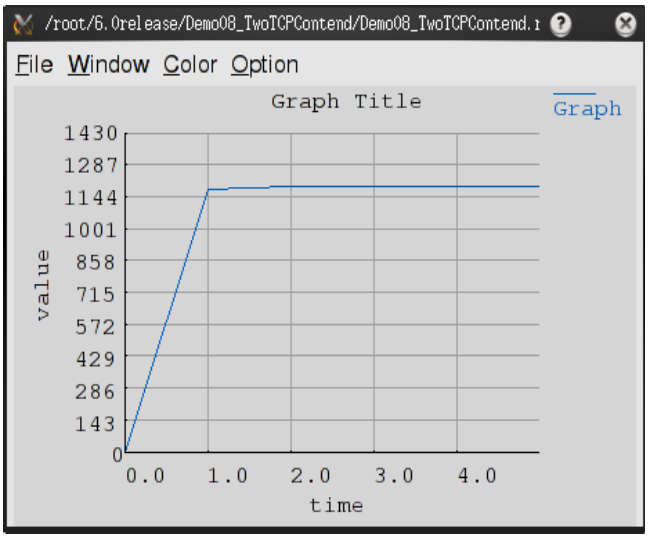
To start the playback, the user can left-click the start icon (▶) of the time bar located at the bottom. The animation player will then start playing the recorded packet animation.

The following figure shows these control buttons.

The following figure shows the animation player when it is playing a packet animation trace file.



While the packet animation player is running, the user can also launch the performance monitor. In this way, the performance monitor will dynamically plot performance curves of some logged performance metrics as the time is progressing. For example, a TCP connection's achieved throughput or a link's utilization can be plotted. The time used by the performance monitor and the packet animation player are synchronized with each other. The following figure shows the performance monitor when it is plotting a performance curve over time.



The performance plotter is plotting a performance curve over time.

Note that the performance monitor can also be used to plot static performance graphs (i.e., the performance curves during a fixed time interval) and this can be easily done. When the packet animation player is not playing (i.e., stopped), the user can directly move the time knot to any desired time. This will cause the performance monitor to plot static performance curves over a time interval that starts at the specified time.

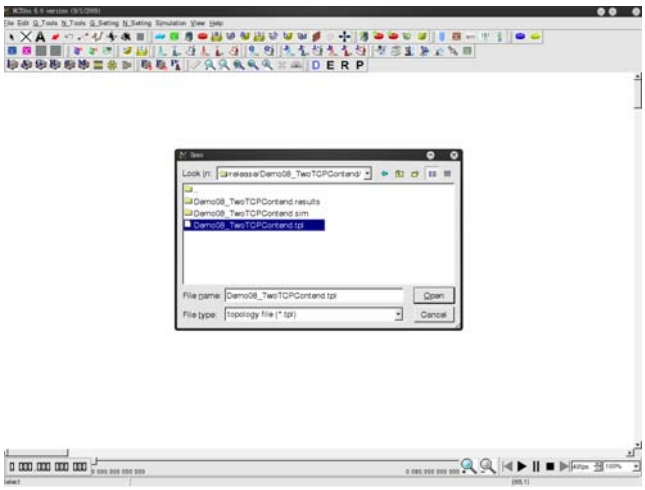
At this stage, the whole process of using NCTUns to perform a simulation case is over. The user may quit the GUI program at this time while leaving the dispatcher and coordinator program running in the background.

Post Analyses

When the user wants to review the simulation results of a simulation case that has been finished before, he (she) can run up the GUI program again and then open the case's network topology file (.tpl).

The user can switch the mode directly to the "Play Back" mode. The GUI program will automatically reload the simulation results (including the packet animation trace file and some performance log files). Because the animation file size is usually very large, the loading process may take a while for a large case.

After the loading process is finished, the user can use the control buttons located at the bottom of the screen to view the animation, just like what he (she) would do when a simulation job is done.



Simulation Control Commands

During a simulation, a user can have control over its execution. Job control commands are grouped in the "Simulation" menu. The following explains the function of each job control command.

- **Run:** Start to run the simulation
- **Pause:** Pause the currently-running simulation
- **Continue:** Continue the simulation that was paused
- **Stop:** Stop the currently-running simulation
- **Abort:** Abort the currently-running simulation. The difference between "Stop" and "Abort" is that a stopped simulation job's partial results will be transferred back to the GUI program. However, an aborted simulation job's partial results will not be transferred back. Instead, they will be immediately deleted on the simulation server to save disk space.
- **Reconnect:** The Reconnect command can be executed to reconnect to a simulation job that was previously disconnected. All disconnected jobs that have not finished their simulations or have finished their simulations but their results have not been retrieved back to the GUI program by the user will appear in a session table next to the "Reconnect" command. When executing the "Reconnect" command, a user can choose a disconnected job to reconnect from this session table.
- **Disconnect:** Disconnect the GUI from the currently-running simulation job. The GUI can now be used to service another simulation job. A disconnected simulation job will be given a session name and stored in a session table.
- **Submit as Background Job:** Submit a job to the dispatcher without first running up it in the GUI and then immediately disconnecting it. Its net effect is the same as first running up a simulation job and then immediately disconnecting the GUI program from it. A job submitted in this way is called a "background job." It does not need the GUI's support (or occupy the GUI) while its simulation is ongoing. A background job may wait in the dispatcher's job queue if currently there is no available simulation server to service this job. Whenever a simulation server becomes available, on behalf of the GUI program that submitted this background job, the dispatcher will automatically start the background job's execution on that simulation server.

Background Job Management

As explained before, a background job is a job submitted by executing the "Submit" command. After being submitted, a background job may (1) wait in the dispatcher's job queue waiting for an available simulation server to service it, (2) be currently executed by a simulation server, or (3) may have finished its simulation. Depending on which state a background job is currently in, a user can use appropriate commands to either cancel it, reconnect to it, or retrieve its simulation results.

Summary

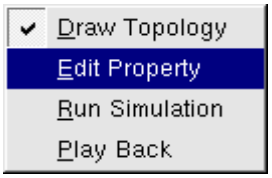
In this chapter, we present how to use NCTUns to quickly build a simulation case. The package installation process and environment variables setting are covered in detail. We also provide a quick tour to help users learn how to run up his (her) first simulation case. In later chapters, the functions and capabilities of the GUI program will be explained in more detail. In the next chapter, we will begin with the topology editor.

3. Topology Editor

Building a network topology is the first step toward running a simulation. It can be easily done through the use of the topology editor of NCTUns. This chapter will show you how to quickly build a network topology by using the topology editor.

Four Operating Modes

Menu->File->Operating Mode->(Draw Topology, Edit Property, Run simulation, Play Back)



NCTUns has four operating modes. A user needs to switch the mode at proper times to make the topology editor work correctly.

Mode 1: Draw Topology. In this mode, a user can add new nodes/links or delete nodes/links to construct a network topology. If the moving path of a mobile node needs to be specified before the simulation starts, this path specification job must be done in this mode. Note that for the mobile nodes in the active and tactic mobile ad hoc networks and the mobile cars in the Intelligent Transportation Systems (ITS), their moving paths are not specified before the simulation starts but rather are dynamically changed during simulation. More information about these two types of networks (i.e., Tactic and ITS) will be discussed in later chapters.

Mode 2: Edit Property. In this mode, a user can edit the property of a node. For example, he (she) can specify which protocol modules should be used inside a node and what values should be used for the parameters needed by these modules. A user can also specify the application programs that should be run up on a node during simulation. However, in this mode a user can no longer change the topology of the network that has been fixed in Mode 1.

Mode 3: Run Simulation. In this mode, a user can run/pause/continue/stop/abort/disconnect/reconnect/submit a simulation in this mode. No simulation settings can be changed in this mode.

Mode 4: Play Back. After a simulation is finished, the .ptr packet animation trace file will be automatically sent back to the GUI program. The GUI program will then automatically enter into this mode. In this mode, the user can play/pause/continue/stop the packet transfer animation.

The (

) buttons on the tool bar correspond to these four different modes, respectively. If a user needs to switch the operating mode very often among these modes, it will be more convenient to click one of these buttons to switch into that chosen mode. At any given time, one of these buttons will be displayed in blue color. This reminds the user of the current mode. When a simulation is running, all of these buttons will be temporarily disabled. They will be automatically enabled when the simulation is finished, stopped, or aborted.

Adding Nodes with the Tool Bar

The tool bar contains many types of network device icons, including host  , hub  , router  , switch  , 802.11(b) wireless LAN (WLAN) access point  , 802.11(b) WLAN ad-hoc mode mobile node  , 802.11(b) WLAN infrastructure mode mobile node  , 802.11(a) wireless LAN (WLAN) access point  , 802.11(a) WLAN ad-hoc mode mobile node  , 802.11(a) WLAN infrastructure mode mobile node  , multi-interface mobile node (having one 802.11(a) WLAN ad-hoc mode interface, one 802.11(a) WLAN infrastructure mode interface, one 802.11(b) WLAN ad-hoc mode interface, one 802.11(b) WLAN infrastructure mode interface, one 802.11(p) OBU, one GPRS radio, one DVB-RCST satellite interface, and one 802.16(e) mobile station)  , obstacle (can block/attenuate wireless signal, block mobile node's movement, and block mobile node's view)  , Wide Area Network (WAN) abstraction  , host subnet  , and five emulation-related types of network device icons -- external host  , external WLAN ad-hoc mode mobile node  , external WLAN infrastructure mode mobile node  , external router  , and virtual router  . As one sees, the icons of most emulation-related nodes contain an "E", which reminds that these nodes represent external real-life nodes used in an emulation case. The icon of the virtual router contains a "V," which indicates that it can represent a real router or be virtu-

alized by either a layer-2 switch or a direct Ethernet link. More information on emulation can be found in later chapters.

Other network device icons include QoS DiffServ network's boundary router , QoS DiffServ network's interior router , GPRS network's GGSN device , GPRS network's SGSN device , GPRS network's base station , GPRS network's phone (radio) , GPRS network's pseudo switch , optical network's circuit switch , optical network's burst switch , optical network's protection ring creation tool ,optical network's edge router-to-edge router's shortest (light) path creation tool , 802.11(b) dual-radio mesh OSPF (using the OSPF routing protocol) access point , 802.11(b) dual-radio mesh STP (using the Spanning Tree Protocol) access point , 802.11(b) dual-radio mesh multi-gateway switch , 802.11(e) WLAN infrastructure mode mobile node , and 802.11(e) WLAN access point .

The network device icons for IEEE 802.16(d) WiMAX networks are classified into two groups. The first group is for the PMP mode and includes 802.16(d) Base Station (BS) in PMP mode , 802.16(d) Gateway Subscriber Station (SS) in PMP mode , and 802.16(d) Host Subscriber Station in PMP mode . The second group is for the mesh mode and includes 802.16(d) Base Station in mesh mode , 802.16(d) Gateway Subscriber Station in mesh mode , and 802.16(d) Host Subscriber Station in mesh mode . The functions of these devices will be explained in a later chapter for IEEE 802.16(d) WiMAX networks.

The network device icons for IEEE 802.16(e) WiMAX networks include 802.16(e) Base Station (BS) in PMP mode , 802.16(e) Mobile Station (MS) in PMP mode . The functions of these devices will be explained in a later chapter for IEEE 802.16(e) WiMAX networks.

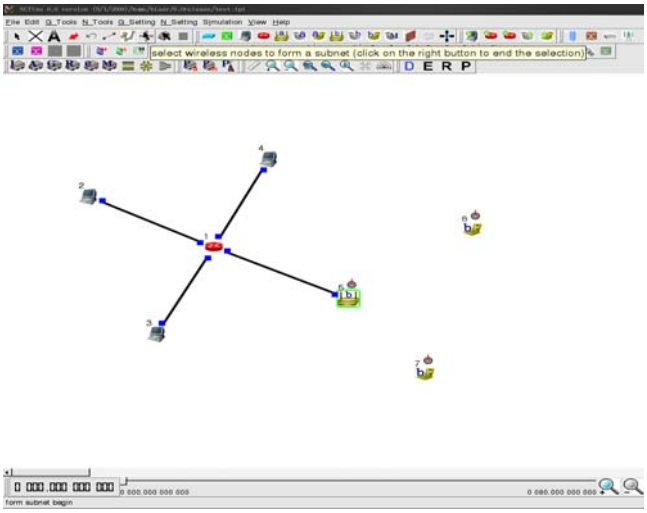
The network device icons for IEEE 802.16(j) WiMAX networks are classified into two groups. The first group is for the transparent mode, including 802.16(j) MR_BS in transparent mode , 802.16(j) fixed RS in transparent mode , and 802.16(j) MS in transparent mode . The second group is for the non-transparent mode, including 802.16(j) MR_BS in non-transparent mode , 802.16(j) fixed RS in non-transparent mode , and 802.16(j) MS in non-transparent mode . The functions of these devices will be explained in a later chapter for IEEE 802.16(j) relay WiMAX networks.

The network device icons for DVB-RCST satellite networks include DVB-RCST service provider , DVB-RCST Network Control Center (NCC) , DVB-RCST Return Channel Satellite Terminal (RCST) , DVB-RCST feeder , DVB-RCST traffic gateway , DVB-RCST satellite , and DVB-RCST pseudo switch . The functions of these devices will be explained in a later chapter for DVB-RCST satellite networks.

The icons for wireless vehicular networks in Intelligent Transportation Systems are divided into two groups. The first group is for constructing a road network and includes ITS road segment , ITS crossroad , and ITS road merger , ITS Road-Side Unit (RSU) with an 802.11(p) interface . The second group is about ITS cars that run on a constructed road network, which includes ITS car with an 802.11(b) infrastructure mode interface , ITS car with an 802.11(b) ad-hoc mode interface , ITS car with a GPRS radio , ITS car with a DVB-RCST satellite interface , ITS car with an 802.16 (e) interface , ITS OBU with an 802.11(p) interface (agent-controlled) , ITS OBU with an 802.11(p) interface (module-controlled) , and ITS car with all of the above different interfaces . The functions of these icons will be explained in a later chapter for ITS wireless vehicular networks.

A user can choose a device by clicking the mouse's left button on its icon on the tool bar. He (she) then moves the mouse cursor to a location in the working area and then clicks again to place the chosen device at the current position of the cursor.

A network topology consists of not only nodes but also links between them. Links can be added to the network topology easily. A user can click the link icon , move the cursor to one device node, click the device node to fix one end of the link, drag the link to another device node, and then release the mouse button to fix the other end of the link. The user will see that a straight line between the two selected nodes is created. The following figure shows the network topology after the user has placed several links in the working area to connect these nodes together.



When nodes and links are added to or deleted from a network topology, a node's ID and the ID of its ports (interfaces) will be automatically assigned and adjusted by the GUI program. The GUI program will re-number each node's ID when any node is deleted from the topology to make sure that node IDs are continuously numbered. For a node, when one of its link is deleted, the GUI program will also re-number the IDs of all of its ports (interfaces) to make sure that port IDs always start at 1 and are continuously numbered on a node.

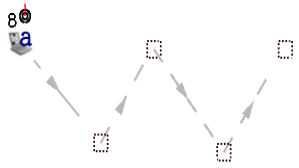
To see where a mobile node has moved to during an animation playback, a node's ID is displayed next to its icon at all times on the screen. A port (interface) of a fixed-network node is represented by a blue box. For wireless interfaces such as those used by WLAN mobile nodes, WLAN access points, GPRS phones, and GPRS base stations, they are represented by the wireless signal propagation waves , which indicates the used antenna and it's direction. By default, the used antenna is an omni-directional antenna. In this case, the antenna icon is shown as 360-degree circles. If a 3db-beamwidth 60-degree directional antenna is used, only 60 degrees out of 360 degrees of the above antenna icon will be shown and its pointing direction is the pointing direction of the directional antenna. A 3db-beamwidth 120-degree directional antenna is displayed in the similar way. More information about directional antennas will be discussed in a later chapter.

When the user switches the mode to the "Edit Property" mode, the GUI program will automatically generate and assign an IP and MAC addresses to each port (interface) of a layer-3 device (e.g., a host or a router). In this mode, if the user moves the mouse cursor and place it over the interface (either a blue box or an antenna icon) for a while, the port's information (i.e., its port ID and assigned IP address) will be shown on the screen. Note that the information shown for a layer-1 port (e.g., a hub port) or layer-2 port (e.g., a switch port) contains only the port ID information. This is because such ports do not have IP addresses assigned to them.

In a real-world network environment, a mobile node may move. A mobile node may be an IEEE 802.11(a) WLAN ad-hoc mode mobile node, an IEEE 802.11(a) WLAN infrastructure mode mobile node, an IEEE 802.11(b) WLAN ad-hoc mode mobile node, an IEEE 802.11(b) WLAN infrastructure mode mobile node, an multi-interface mobile node, external WLAN ad-hoc mode mobile node (for emulation purposes), and external WLAN infrastructure mode mobile node (for emulation purposes), a GPRS phone, an 802.11(e) WLAN infrastructure mode mobile node, a 802.16(e) mobile station (MS), a DVB-RCST Return Channel Satellite Terminal (RCST), or an 802.11(p) On-Board Unit (OBU). To specify the moving path of such a node, a user first selects the moving path tool icon on the tool bar. He (she) then clicks the mobile node and start dragging and clicking the mouse's left button repeatedly to construct the whole moving path. This operation continues until the user clicks the mouse's right button. Note that for an ITS OBU (i.e., a car), its moving path is dynamically determined during simulation rather than be specified before simulation.

A moving path is composed of a sequence of turning points and segments. After a moving path is constructed, any of its turning points can be easily moved by the mouse to any place to adjust the shape of the path. Each turning point is represented by a grey dashed square box and contains the (X-loc, Y-loc, arrival time, pause time, moving speed to the next point) information. This information can be changed by double-clicking the box in the "Edit Property" mode.

Suppose that a user wants to change the location of a turning point, he (she) can click the mouse's left button on the box, hold it, and then drag it to any place. When a mobile node is moving from one point to the next point (i.e., moving on a segment), its moving speed is fixed. If a user moves the icon of a mobile node rather than one of its turning point boxes, its whole moving path will be moved.



There are several other tools on the tool bar. They are select , delete , label , arrow , undo , ruler , zoom in , zoom out , zoom into an area , view the whole field , set the zoom scale factor to 1 , specify physical-layer and channel model parameter , and protractor: measure the angle between a specified line segment and the horizon .

The “select” function is the most basic operation. If a user wants to move a device icon, he (she) must select this tool first. He (she) then presses the mouse’s left button on the device icon, holds it, and then drags it to the desired place. In addition, if a user wants to configure a device in the working area, he (she) should use the “select” tool to double-click it.

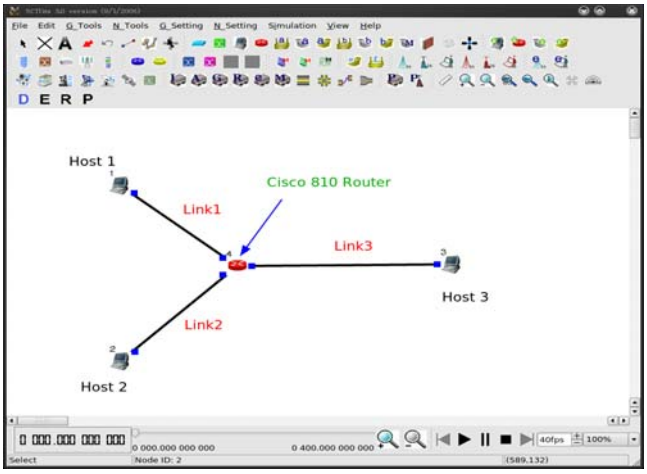
The “delete” function can delete a touched node and all the links connected to it.

The “undo” function can undo the last “delete” operation. It is a useful function because human sometimes make mistakes and it may take much time and effort to recover from a mistake. For example, if a user mistakenly deletes a router that has 20 links each connecting to a host, the router and these 20 links will be deleted. To recover from this mistake without using the “undo” tool, the user will need to add back a router and then add back 20 links. This tedious task can be easily done by immediately executing the “undo” function after the “delete” operation. Note that to undo a “delete” operation, there should be no other operation performed between the “delete” and the “undo” operations. Otherwise, the “undo” function will be disabled by the GUI.

The “label” tool allows a user to enter a label (i.e., annotation) such as “Cisco 8100 router” into the network topology. The user can set the color, font, font style, and font size of the label before a label is added. After a label is added, the user can use the “select” tool to move it to any desired place (e.g., next to a router icon) or change its attributes by double-clicking it. Adding labels to a network topology can make it more readable.

The “arrow” tool allows a user to add an arrow into the network topology. Adding an arrow point to a device icon can highlight the pointed device. Normally, an arrow is accompanied by a label to describe the pointed device. An arrow is added in the same way as a link. The user clicks and holds the mouse’s left button on one place to fix the tail of the arrow. Then he (she) drags the mouse to the desired position and then releases the mouse button to fix the head of the arrow.

After an arrow is added, a user can move it in three different ways. First, the user can use the “select” tool to just move the head of the arrow. Second, the user can use the “select” tool to just move the tail of the arrow. Third, the user can move the entire arrow by clicking the mouse’s left button on the middle of the arrow, holding the button, and then dragging the mouse. To change the color and width of an arrow, a user can use the “select” tool to double-click any part of the arrow. The following figure shows an example network where labels and arrows are added to make the network more readable.

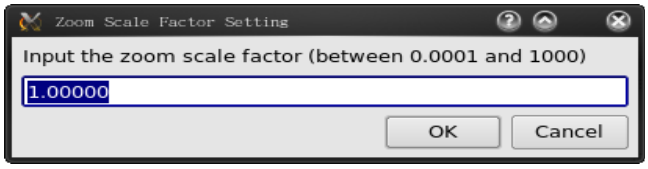


An example network in which labels and arrows are used

The operation of the ruler is the same as creating a link between two device nodes. A message box will show up displaying the distance (in meter) between the two selected nodes. It is primarily used to place WLAN mobile nodes, WLAN access points, GPRS phones and base stations, WiMAX subscriber stations and base stations, etc. at proper locations so that their wireless signals purposely can or cannot reach each other as planned.

Several zoom in or zoom out tool buttons are provided to allow the user to see the network topology in a suitable view. The functions of some of these buttons are also provided as commands located in **Menu->View**. After choosing the “Zoom in to an area” tool, a user can use the mouse to select a rectangular region and zoom into it. Selecting an area is done by clicking the mouse’s left button, hold it, drag it to the diagonal corner of the area, and then release it. Normally, after seeing the details of an area, a user may want the zoom scale factor to return to the default value of 1. This operation can be done by using the “Set the zoom scale factor to 1” tool button. If a zoom scale factor other than 1 needs to be set, a

user can execute the **Menu -> View -> Set Zoom Scale Factor** command. The following figure shows the dialog box of this function.



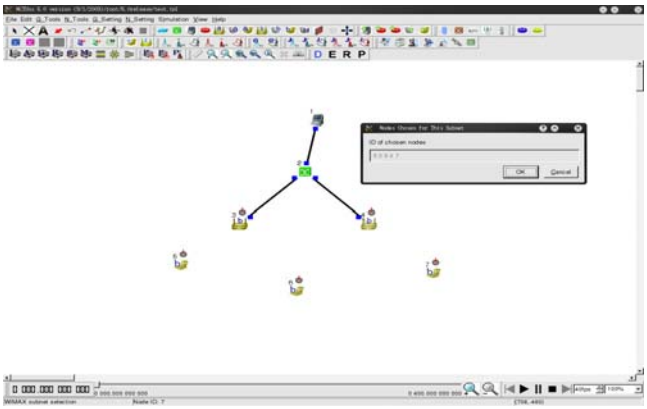
Form a Wireless Subnet

The "Form wireless subnet" ( ) tool is a very important tool for setting up simulation cases of wireless networks.

Recall that to save the GUI user's time and effort, the GUI program automatically identifies subnets and assigns IP and MAC addresses to layer-3 interfaces. The GUI program performs this job very well on a wired network because all nodes (including host, switch, hub, router, etc.) on such a network are connected and therefore all subnets on such a network can be identified. However, for a wireless network where mobile nodes are isolated nodes, the GUI program does not have the intelligence to know which mobile nodes and IEEE 802.11(a/b) access points should belong to the same subnet. Without such information, because the GUI program cannot determine the ID of the subnet to which a mobile node should belong, the GUI program cannot automatically assign an IP (1.0.subnetID.hostNum) and MAC address to the mobile nodes.

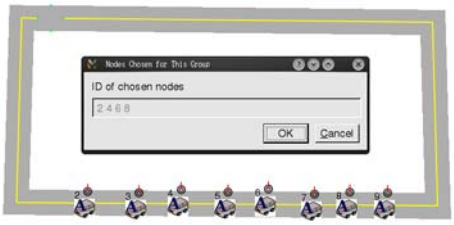
To solve this problem, the GUI program provides the "Form wireless subnet" ( ) tool for the user to manually group related wireless mobile nodes together to form a subnet. To do so, the user first selects this tool and then uses the mouse's left button to sequentially click all required nodes. When all required nodes have been selected, the user clicks the mouse's right button to end the selection process. The user must use this tool to select all required nodes to form a subnet. For example, for an IEEE 802.11(b) infrastructure mode wireless network, the user must select all relevant mobile nodes and access points to form a subnet. The following figure shows an example usage of this tool. For this network, the user should use this tool to select the three mobile nodes and the two access points to form a subnet. With this information, now the GUI program knows that the three mobile nodes all reside on the subnet where the access points reside. As such, the IP and MAC addresses of these mobile nodes can be assigned automatically.

The "Form wireless subnet" ( ) tool is necessary for various wireless networks, including IEEE 802.11(a/b) infrastructure mode and ad hoc mode wireless networks, IEEE 802.16(d) WiMAX wireless networks, DVB-RCS satellite networks, GPRS networks, etc. The detailed operations for these wireless networks will be illustrated in later chapters.



Form an ITS Car Group

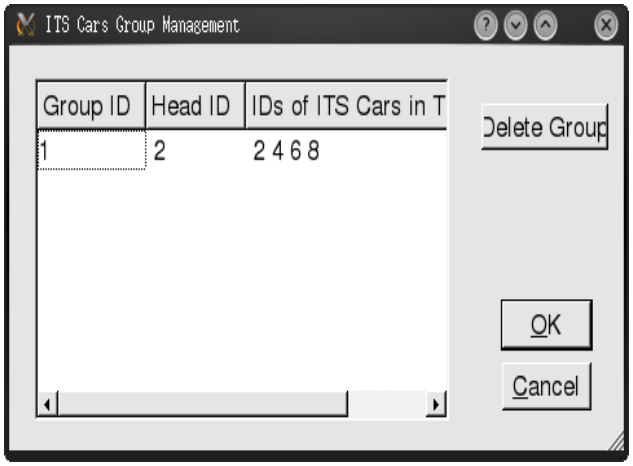
The "Form ITS cars group" ( ) tool is used for a user to group several ITS cars into a fleet, which is called a car group in NCTUns. The cars in the same group will sequentially follow the route taken by the head car of the group during simulation. Forming a car group in NCTUns is easy. One first left-clicks the icon of this tool on the GUI tool panel. He (she) then left-clicks all the icons of cars in the working area that are chosen to form the same car group. To end the selection of cars, one can right-click the mouse and a dialog box showing the IDs of the chosen cars will pop up.



One should note that the first car that is chosen during the selection procedure will be automatically designated as the head car (leading car). Selecting cars into a car group should conform to the following rules.

First, the cars that are chosen to form the same car group must be on the same road. More specifically, all of them must be on the same road between two turns. Second, they must be selected beginning with the head car from left to right or from right to left without jumping back and forth. Once a car group is formed, each of them will try to follow the route taken by its preceeding car during simulation. This feature is useful for studying inter-vehicle communication among the cars in a car group.

To manage the created car groups, one can perform the **"Manage ITS cars group"** tool, which is at **"Menu -> N_Tools -> ITS Network -> Manage ITS cars group."** This command provides an interface to view the information of a car group and delete a car group, which is shown in the following figure.

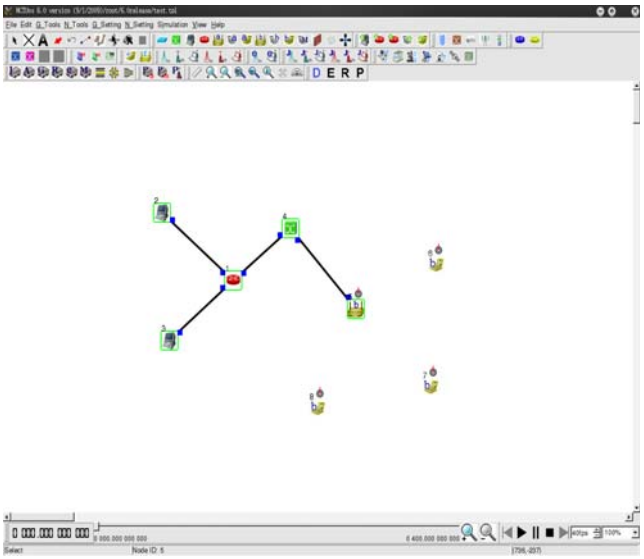


Selecting a Group of Nodes

To save time and effort, a user can select a group of nodes and then apply an operation to all of them. The operations that can be applied to a group of nodes include (1) move and (2) delete.

Using the select tool, a user can select a single node by clicking the mouse's left button on the node. To select multiple nodes, the user can hold the "Ctrl" key while clicking these nodes. Another method is to use the select tool to draw a rectangle area to select all nodes in that area. To draw a rectangle area, when the select tool is used, the user can click the mouse's left button on one point, hold the button, and then drag it to another point. The following figure shows a possible selection result.

To facilitate selecting a large number of nodes of the same kind, several commands are provided in the Edit command menu for various types of networks.



A group of nodes can be selected.

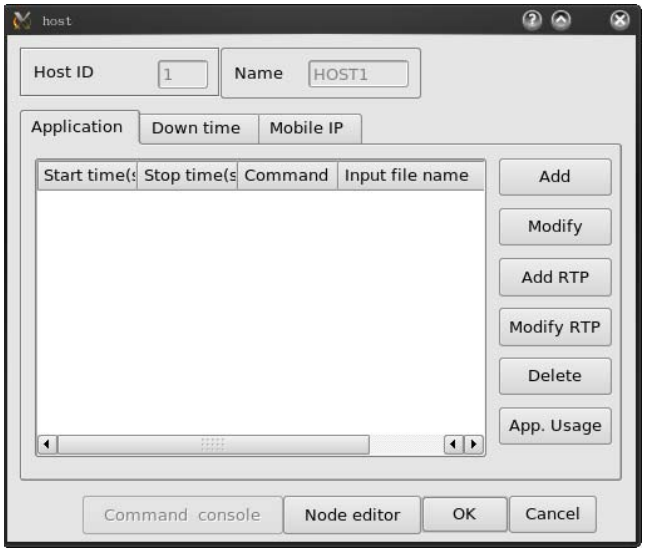
Editing the Attribute of Nodes

After nodes are added, a user can enter the "**Edit Property**" mode to set the detailed attributes of any node by double-clicking its icon. Several attributes and functions such as **[Application]**, **[Down Time]**, and **[Command Console]** are provided for many kinds of devices (see the following host dialog box). Therefore, we present their usages here.

Under the **[Application]** tab, a user can specify which application program should be run on this node. He (she) can put the command string into the "command" field. In addition to the command string, the start time, stop time, and argument of the specified program can also be set. After an entry is added, the user can use the "Modify" button to modify the entry or use the "Delete" button to delete that entry. The "Add RTP" and "Modify RTP" buttons are for RTP simulations. They will be explained in a later chapter specific to RTP. The following shows the popped-up dialog box after the "Add" button is pressed.

If the application program needs to read a configuration file when it is executed, the absolute file path and file name of its configuration file must also be entered with all other information. Otherwise, the GUI program will not have the intelligence to also move the needed configuration file to the remote (or local) simulation server machine. Specifying the absolute file path and file name is best done via the "browse" function in the dialog box of the "Add" command.

For example, suppose that when the stg application program is executed, it wants to read in a configuration file named trace.cfg and this file is located in /usr/local/testuser. Then



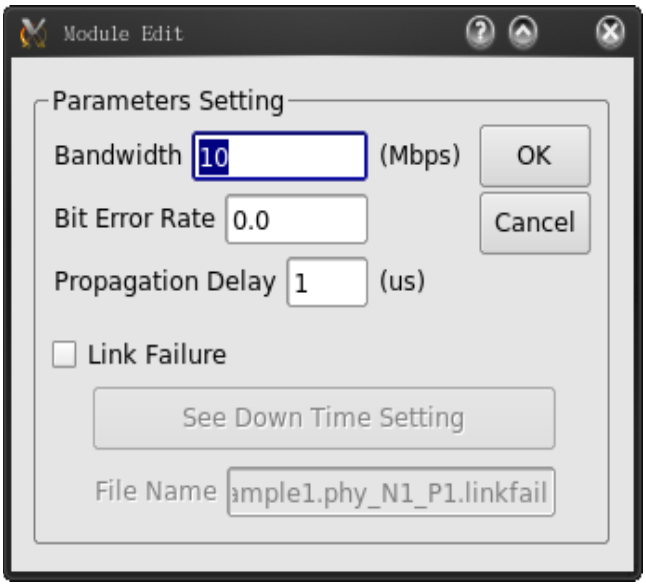
The dialog box of hosts

the entered command string should be something like “stg -i trace.cfg ...” and the “Input file name” field should be “/usr/local/testuser/trace.cfg,” which can be completed by using the “browse” function.

Note that the purpose of providing the absolute file path and file name in the “Input file name” field is for the GUI program to successfully locate it and transfer it to the simulation server machine. On the simulation server machine, the transferred file is placed in the same directory as all other simulation description files such as *.tcl. Therefore, the absolute file path of this file (e.g., /usr/local/test.cfg) should not be given in the command string as an argument to the application. Rather, only its file name (i.e., test.cfg) should be given in the command string.

For example, the command string should not be something like “stg -i /usr/local/testuser/trace.cfg ...”. This is because the GUI machine and the simulation machine may be different machines and use different file systems. An absolute file path used in the GUI machine may refer to nothing on the simulation machine. Since the simulation engine will store the specified configuration file in the working directory of this simulation case, which is also the working directory of all forked application programs for this case, the file name given to the application program can be and should be the file name only without any path specification.

As for the **[Down time]** tab, a user can set the intervals during which the node is down (cannot send and receive any packet). The down time periods specified here will be propagated and set in the PHY (or WPHY) modules of all of the node’s interfaces. This is because the PHY (or WPHY) modules are the right place to disable or enable the transmission and reception of packets. The dialog box of the Phy module is shown below.

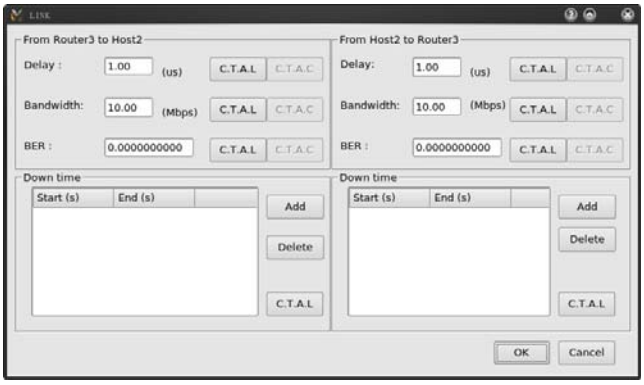


The PHY module in the node editor.

To enable the down time setting of an interface, a user needs to open the node’s node editor, double-click that interface’s physical-layer module (PHY, WPHY, AWPHY or OPT_PHY), and make sure that the “Link Failure” option is checked. If that option is not properly checked, an interface’s down time periods that come from either a node or a link will not take effect during simulation. To see the current down time setting for the interface, the user can click the “See Down Time Setting” button.

A user can also set the down time periods of a link. By double-clicking a link, a link property dialog box will show up. In the dialog box, a user can set the link’s bandwidth, signal propagation delay, bit-error-rate (BER), and down time periods for each direction of the link. If the link is an optical link with multiple channels, the same dialog box can be used to set the property of each channel. The following figure shows the property dialog box of an optical link.

The “C.T.A.C” button stands for “Copy To All Channels (of this selected link).” This function is enabled only when the user is specifying the property of a channel of an optical link. (When double-clicking an optical link, the GUI will first ask the user which channel of the link he (she) wants to configure.) Clicking this button will copy a field’s current value to the same fields of all channels of the selected link.



The link property dialog box.

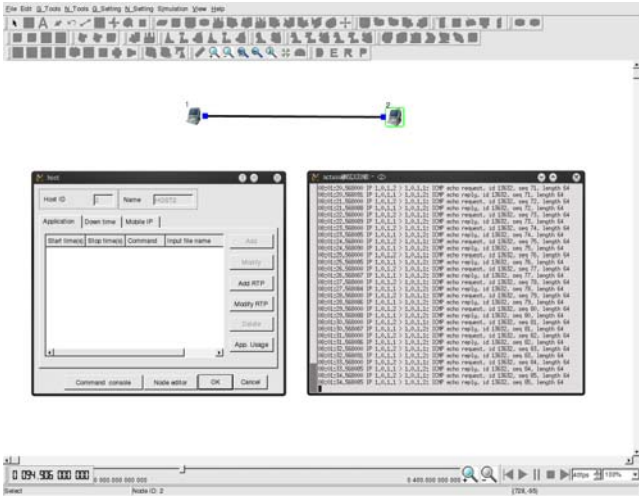
However, the same fields of the channels of all other links will not be affected. This button can save a user a lot of time when the user wants to change the property of all channels of an optical link to a specific setting.

The "C.T.A.L" button stands for "Copy To All Links (and to all of their channels)." Clicking this button will copy a field's current value to the same fields of all links (and to all of their channels if they are optical links) in the simulated network. This button can save a user a lot of time. For example, if a user wants to set the bandwidth of all links to 20 Mbps, he (she) can open up any link's property dialog box, change the bandwidth from 10 to 20 Mbps, and then click the "C.T.A.L" button next to the Bandwidth field. The bandwidth of all links (and their channels if they have any) in the simulated network will be changed to 20 Mbps.

Since links are bidirectional, a user can separately specify the down time periods for each direction of a link. The down time periods specified for a direction of a link (say, from node A to node B) are automatically propagated to and set in the physical-layer module (e.g., PHY) of node A. Therefore, the down time periods set in an interface's physical-layer module actually is the union of the down time periods of the node to which this interface attaches and the down time periods of the link to which this interface connects.

In addition to the down time information, other attributes of a link are also automatically propagated to the appropriate modules of the two nodes that connect to this link. For example, the bandwidth, signal propagation delay, and BER are all propagated to and set in the corresponding physical-layer modules. Note that this automatic link parameter propagation process will override the settings specified by the user in the node editor for these physical-layer modules. The GUI program adopts this design because it is more intuitive to set a link's attributes by double-clicking it. Individually invoking the node editors of the two nodes that connect to a link to set their link attributes is less intuitive and may result in inconsistent settings.

[Command console] button is provided in the dialog boxes of several nodes. This function is enabled only when a simulation is running. A user can use this console to log into the current node (the node whose dialog box is shown right now). A xterm terminal window will appear. In this terminal window, a user can run the tcpdump program to capture packets passing through one of this node's interface or launch application programs on this node at run time. The following figure shows a command console usage in which a tcpdump is capturing packets.



A command console can be invoked during a simulation. In this case, a tcpdump is capturing packets in this command console.

For a router, suppose that the user wants to capture the packets flowing through one of its interfaces. Further assume that this particular interface is assigned 1.0.2.3 IP address. The user can first execute "ifconfig -a" command to find out the information about all of the router's interfaces. From the output, the user can find the name of the desired interface which is assigned 1.0.2.3. In NCTUns, an interface's name is in the ethXXX format, where XXX is the interface's port ID. After finding the name of the desired interface, the user can execute the following command "tcpdump -i ethXXX" to launch the tcpdump program. Since the launched tcmdump is the real-life tcpdump program, all tcpdump options are supported. This means that the user can use any packet filtering rule such as "tcpdump -i eth2 src 1.0.2.1" or "tcpdump -i eth3 -w tdump.log dst port 8002."

The command console is a very useful function. A user can use this console to launch application programs at run time to generate traffic. For example, while the simulation is running, the user can open a receiving node's command console to launch the "rtcp -p 8000" TCP receiving program and then open a sending node's command console to launch the "stcp -p 8000 1.0.1.2" TCP sending program, assuming here that the receiving node has an interface assigned 1.0.1.2 IP address.

In addition, executing the ping command in a command console is very useful. Doing so can help a user find out whether the routing path between two nodes has been correctly set up during simulation.

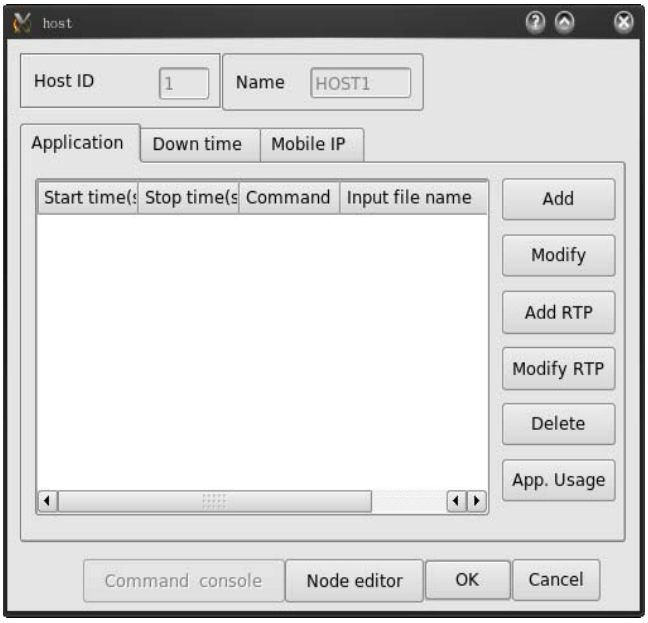
The simulation engine of NCTUns is a discrete-event simulation engine. Thus, its simulation clock may advance faster than the real-world clock. To allow the user to take his (her) time to type commands in a command console, it is suggested that the speed of the simulation is set to "As fast as the real-world clock," which can be done in **Menu -> G_Setting -> Simulation -> [Speed tab]** rather than the default "As fast as possible.**"**

To quit a command console, a user can use the mouse to kill the xterm window. All command consoles will be automatically killed by the GUI program when the simulation is finished, stopped, aborted, or disconnected.

Note that an output file generated by an application program invoked in a command console will be transferred back to the simulation case's XXX.results directory on the GUI machine. For example, the tdump.log generated by the previous "tcpdump -i eth3 -w tdump.log dst port 8002" command will be transferred and stored in the case's XXX.results directory.

In addition to the above shared tabs, each device may have its own ones. We present them below.

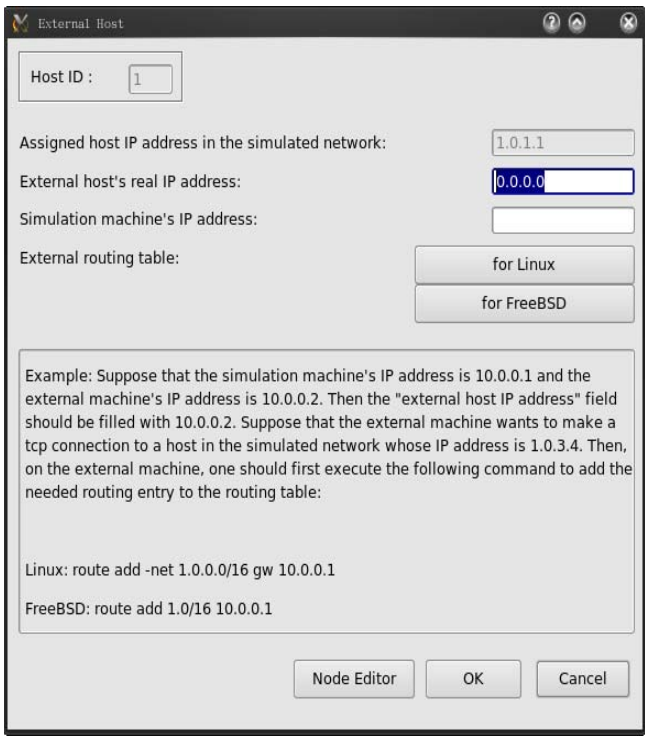
- **Host**



The "Mobile IP" tab is related to the Mobile IP protocol. NCTUns supports the Mobile IP protocol; including both the basic scheme and the advanced route optimization (RO) scheme. The types of nodes involved in Mobile IP are host (correspondent host), mobile node (infrastructure mode), and routers (where the home agent or the foreign agent is running). As such, all of these types of nodes have the "Mobile IP" tab. More details about how to run Mobile IP will be discussed in a later chapter.

The "Add RTP" and "Modify RTP" buttons are for RTP, RTCP, and SDP protocols. A user can use "Add RTP" to specify the various parameters given to a RTP application program. Like the "Modify" button, the "Modify RTP" button is used to modify a command string generated by a previous "Add RTP" operation. The "Delete" button is a general-purpose button and can be used to delete a RTP or non-RTP application entry. More information about how to run RTP will be discussed in a later chapter.

- **External Host, Mobile Nodes, and Router**

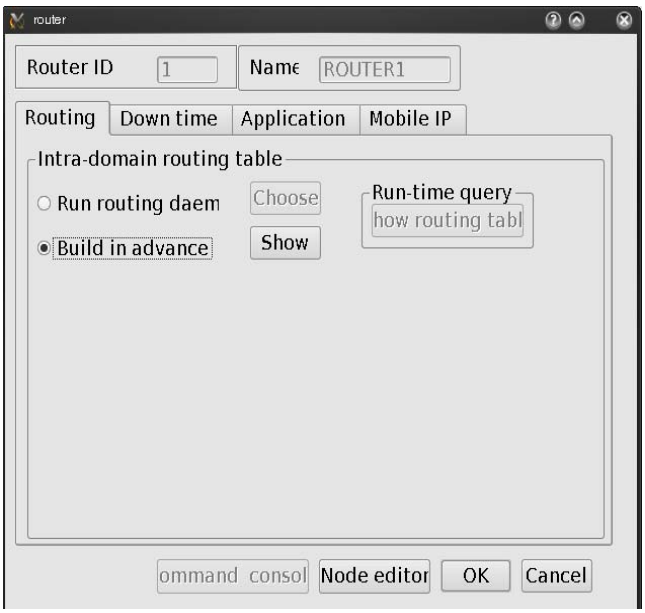


An external host, external mobile node (ad-hoc mode), external mobile node (infrastructure mode), or external router represents a real device in the real world. They are used for emulation purposes. Because emulation is an important function, a separate chapter titled “Emulation” is dedicated to it. Explanations of the usage of these fields will be documented in detail in that chapter.

- **Hub**

Because every port of a hub must use the same bandwidth, one has to specify the link bandwidth used by the ports of the hub in the Bandwidth field.

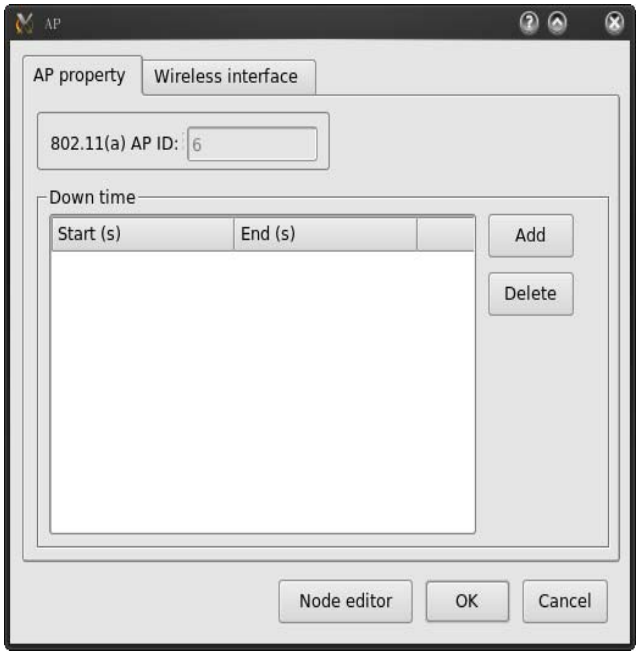
- **Router**



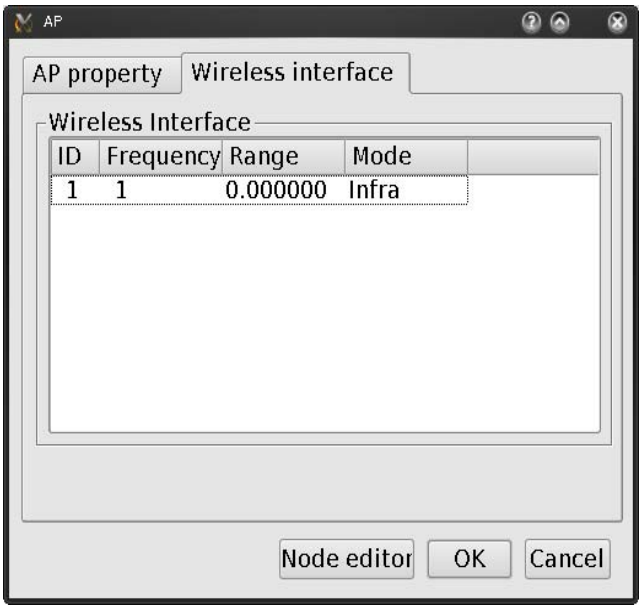
In this dialog box, a user can specify whether all routers in a case should run routing daemons (e.g., RIP, OSPF) to construct their routing tables or their routing tables should be calculated in advance by the GUI program. Run-time routing table content lookup can be performed by clicking the “Show routing table” button when a simulation is running.

- **Switch**

- **Access Point**

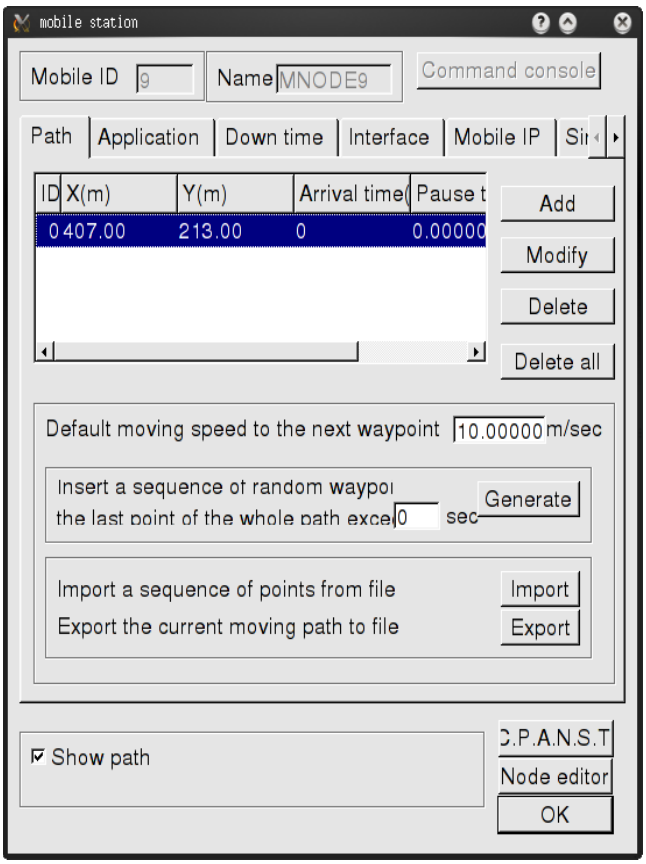


Under the **[AP Property] tab**, a user can set the down time periods for an access point.



Under the **[Wireless Interface] tab**, a user can examine the interface's attributes (e.g., the used frequency channel and the wireless signal transmission range).

- **Mobile Node (Ad-hoc and Infrastructure mode)**



A powerful and flexible configuration dialog box is provided for WLAN mobile nodes. Under the **[Path] tab**, the moving speed, location (X, Y) of each turning waypoint, pause time during which a mobile node stays at the current waypoint can be configured.

To insert a waypoint into the middle of the existing path, the user can first use the mouse to click the appropriate insertion point in the path dialog box and then click the "Generate" button. In addition, the moving speed between the new point and the next point will be automatically calculated so that the next point's arrival time need not be changed.

To generate a random waypoint path, several methods are provided. A user can ask the GUI program to generate random waypoints on the fly; either one point at a time or ask it to keep generating waypoints until the arrival time of the last waypoint exceeds the specified time. A user can also import a mobile node's path from an existing *.mpt file. Each line in an mpt file represents a waypoint and its format is (X_pos, Y_pos, Arrival Time, Pause Time, Moving Speed). This file may be generated by a program (e.g., a vehicle microscopic traffic simulator) or as a result of

exporting a mobile node's moving path. In the topology editor, a user can also drag-and-drop the mouse to directly place a path's waypoints.

Under the **[Single-hop connectivity] tab**, the GUI program will calculate and show at what time this mobile node can/cannot reach other mobile nodes in its single-hop transmission range.

On the other hand, under the **[Multi-hop connectivity] tab**, the GUI program will calculate and show at what time this mobile node can/cannot reach other mobile nodes via multiple hops, through the help of the ad-doc mode forwarding.

These two functions are provided for comparing research results with the ideal results. The outputs of these two functions represent the most accurate and ideal routing paths that only "God" can know and achieve at any time. These two functions are meaningful only when the used wireless module is the simple WPHY, which has a specific transmission range and is not very realistic. When the used wireless module is the advanced AWPHY, which does not have a clear transmission range but is more realistic, the two connectivity functions are not very meaningful.

Under the **[Interface] tab**, a user can examine the interface's attributes (e.g., the used frequency channel and the wireless signal transmission range).

The "**C.P.A.N.S.T.**" button stands for "**C**opy the **P**arameters to **A**ll **N**odes of the **S**ame **T**ype." If a user executes this function, the parameters used by this WLAN mobile node will be copied to all WLAN mobile nodes with the same operating mode (i.e., ad-hoc or infrastructure). That is, the parameter values of all other WLAN mobile nodes with the same operating mode will be replaced by the current one. For example, if the current WLAN mobile node is an ad-hoc mode mobile node, its parameter values will be copied to (and only copied to) all other ad-hoc mode mobile nodes.

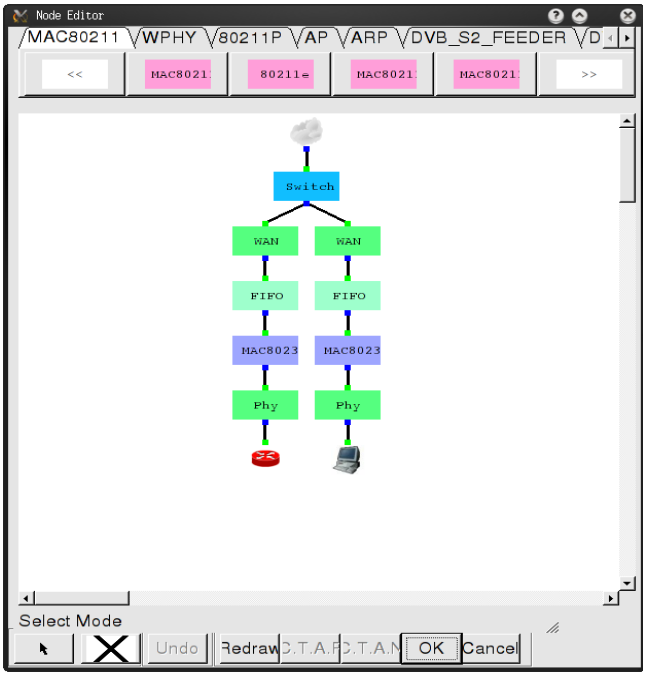
The **"C.P.A.N.S.T."** is a useful function. Suppose that a user wants to compare the performances of two different routing protocols (A and B), he (she) may attempt to test the performances of these two protocol modules under the same network topology and configuration. That is, the initial locations and the moving paths of all mobile nodes in these two cases should be exactly the same; the difference should be only in the used protocol stack.

With this function, this task can be easily done in the following steps. (1) The user first tests the performance of protocol module A in a simulation case. (2) The user executes the **Menu ->File ->Save As** command to save the current case into another one. (3) In the new case, the user invokes any mobile node's node editor to replace protocol module A by protocol module B in that node's protocol stack. (4). The user uses the "**C.P.A.N.S.T.**" button to replace the parameter values (including the protocol stacks) of all other mobile nodes with the new one. (5) Finally, the user runs the new simulation case and obtains the performance results of protocol module B under the same network topology and configuration.

Note that the above task can also be easily done by executing **Menu -> G_Tools ->Export Mobile Nodes and Their Paths to File** and **Menu -> G_Tools -> Import Mobile Nodes and Their Paths from File** commands and **Menu -> G_Tools -> Import Network Traffic Application File** command. Detailed instructions on these commands will be presented later in this chapter.

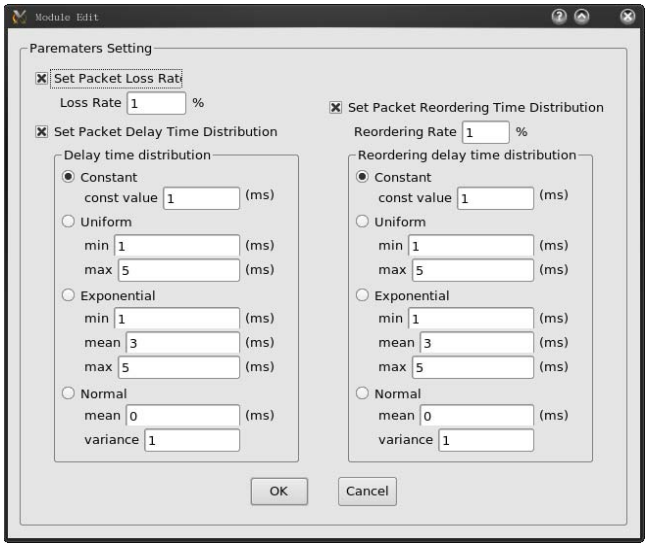
- **WAN (Wide Area Network Abstraction)**

A WAN is a layer-2 node that simulates various properties of a Wide-Area-Network. It can purposely delay, drop, and/or reorder passing packets according to a specified distribution. Inside the simulation engine, a WAN is implemented as a layer-2 switch with only two ports. The packet dropping, delaying, and reordering functions are achieved via the WAN module used inside a WAN node. In a WAN node, a WAN module exists in each of its two ports. It delays, drops, and/or reorders the port's outgoing packets. The forward and backward packets of a flow that traverse a WAN can therefore receive different treatments.



A WAN module exists in each port of a WAN node. The WAN module can purposely delay/drop/reorder its port's outgoing packets.

Inside the parameter dialog box of the WAN module, packet delaying, dropping, and reordering function can be independently used. Supported distributions include constant, uniform, exponential, and normal distributions. The following figure shows the dialog box of the WAN module.



The parameter dialog box of the WAN module.

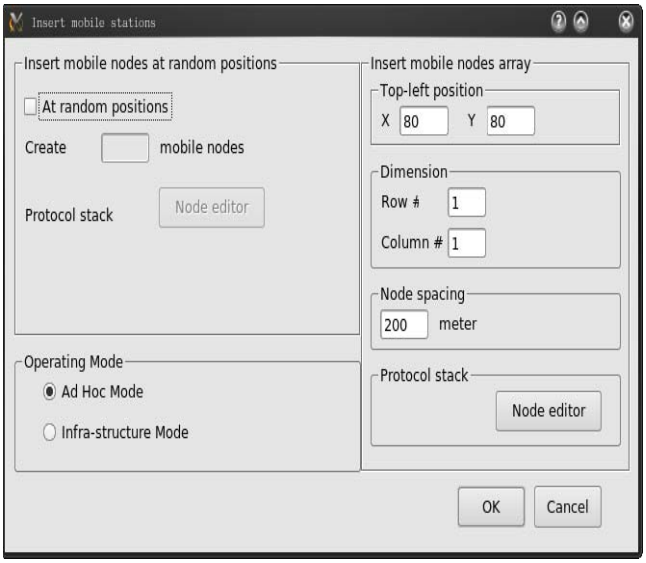
Other methods to add Mobile Nodes

In addition to the simple way by which a GUI user clicks the mouse to add one mobile node at one time, there are several other methods that can be used to add multiple mobile nodes in just one step.

Insert Multiple Mobile Nodes

A user can insert multiple mobile nodes using the same protocol stack and parameter settings by executing just one command. Each kind of wireless networks (e.g., IEEE 802.11(a/b) WLAN, IEEE 802.11(e) WLAN, IEEE 802.16(d/e/j) WiMAX, GPRS, DVB-RCS satellite network, etc.) provides its own command for this purpose and these commands are located in **Menu-> N_Tools.** The following figure shows the dialog box of this command for IEEE 802.11(b) WLAN networks. The added mobile nodes can be placed at random positions or in an M * N array. Their operating mode (ad hoc or infrastructure) can also be chosen.

The user can generate a large number of WLAN mobile nodes that use a protocol stack other than the default one. To do so, the user can first invoke the node editor in this dialog box to specify the protocol stack used by these mobile nodes. If this operation is not done before adding a large number of nodes, the user later may suffer from invoking all mobile nodes' node editors to configure their protocol stacks individually. Fortunately, with the mobile node's "**C.P.A.N.S.T."** function, this tedious task can be easily and quickly done.



The dialog box of the "Insert WLAN Mobile Nodes" command.

Import/Export Mobile Nodes and Their Paths from/to File

These two commands are located in the **Menu -> G_Tools** menu. The import function loads all mobile nodes and their moving paths from a *.mdt file while the export function saves the same information into a mdt file.

It's convenient and useful for a user to save mobile nodes' moving paths to a file and later reload and reuse them. For example, to compare the relative performance of several mobile ad-hoc network (MANET) routing protocols under the same moving pattern, the user can (1) create a simulation case in which mobile nodes move in a desired pattern, (2) export these mobile nodes and their moving paths to a mdt file, (3) create a new simulation case for studying the performance of a different routing protocol, (4) import the same mdt file in each of these simulation case, and (5) use the "Node Editor" button in the dialog box of a mobile node to use the desired routing protocol module, (6) use the **C.P.S.T.A.N** button to replace the parameter values (including the protocol stacks) of all other mobile nodes with this one, (7) finally, run the new simulation case and obtains the performance results of the different routing protocol under the same network topology and configuration.

The format of the mdt file is simple and explained in the file itself. A user can first export the moving paths of a case to a mdt file and then see its content. The import function is very useful for large-scale simulation cases where the number of mobile nodes is very large and the lengths of their moving paths are very long. In such a situation, the mobile nodes' locations and their moving paths may better be generated by a script program, which will save the user a lot of time and effort.

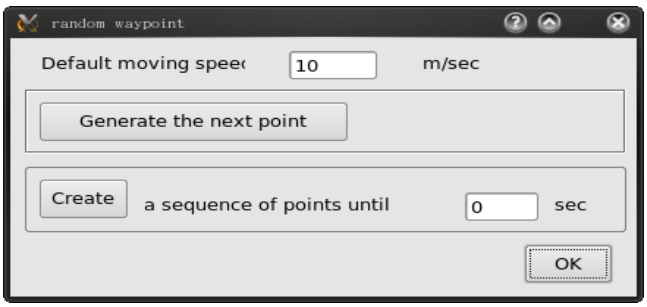
This facility is also very useful for using a special mobility pattern that is not supported by NCTUns. Right now, NCTUns can only automatically generate random waypoints paths for mobile nodes or allow a user to manually specify the moving paths of mobile nodes. However, in some cases, a user may want to study a mobile network with a different mobility pattern.

For example, when using NCTUns to study ITS (intelligent transportation systems) problems, we can first use a microscopic vehicle traffic simulator (e.g., VISSIM) to generate more realistic moving paths of vehicles moving on a highway or in a city. (Note: VISSIM considers the car-following and lane-changing driver's behavior.) A user can write a simple program to convert the moving path log file generated by a third-party program (e.g., in this case, VISSIM) to a mdt file and then import it into the GUI.

After importing a mdt file, the user can further use the "Background Graph" function of NCTUns to paste the used highway or city map onto the background of the topology editor. (This function will be presented later in this chapter) With a background map, when the simulation is executing or when the playback is going on, the user will see vehicles move on highways or roads on the map and vehicles wirelessly exchange their packets via other vehicles. This will give the user a global view of wireless transmission activities on a highway or in a city.

Generate Random Waypoints

The **Menu -> G_Tools -> Generate Random Waypoints for Mobile Nodes** command can be executed to generate random waypoints for all WLAN mobile nodes. There are two ways of doing this job. The first one is to generate the next waypoint randomly for all mobile nodes. When the user clicks the button, one more random waypoint will be generated for every mobile node. The user can press the button continuously to continuously generate more random waypoints. The other way is to automatically generate random waypoints until the arrival time of the last waypoint exceeds the specified time. The following figure shows the dialog box of this function.



Remove All Moving Paths

Executing this function will delete all mobile nodes' moving paths. This will give the user a clean working area to start with. This function is located in **Menu -> G_Tools -> Remove All Moving Paths of Mobile Nodes**.

Import Network Traffic Application File

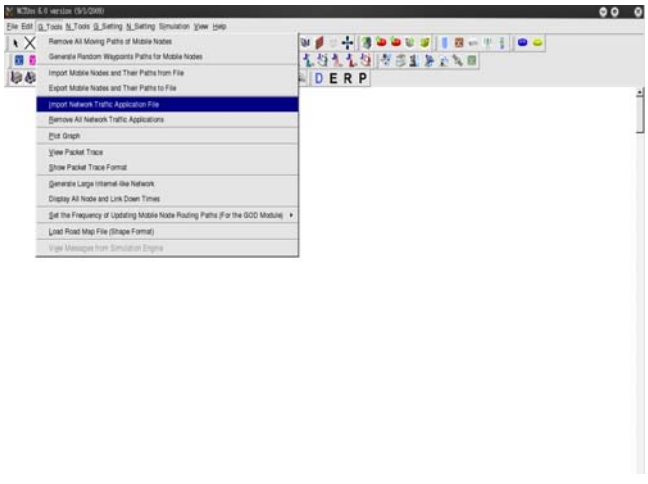
For a large network that has hundreds or thousands of nodes, double-clicking the icon of each of these nodes to enter the application command string for the node is a tedious and time-consuming job. To avoid wasting time and effort on doing this job, the user can use the **Menu -> G_Tools ->**

Import Network Traffic Application File command to read in a traffic configuration file (.tfc). The format of a .tfc file is exactly the same as the .tfc file exported by the GUI program for a simulation case when it switches its mode to "Run Simulation." Therefore, to understand the format of a .tfc file, the user can first make a simple case and then export the case's .tfc file. Each line in the .tfc file specifies the node ID, starting time, ending time, and application command string for a node. The format of a line is $node_(nodeID) start_time end_time application_command_string.

Normally, a .tfc file imported by the "**Import Network Traffic Application File"** command is generated by a script or a program written by the user. Each traffic generator (i.e., application program) command string specified in the .tfc file will be put into the Applications tab of the specified node. This facility can save a user a lot time because now the user need not invoke each node's dialog box individually to enter its used application command strings.

Remove All Network Traffic Application

The **Menu -> G_Tools -> Remove Network Traffic Applications** command does the reverse job. It removes the application command strings of all nodes from their respective Applications tabs. These two commands are useful for large-network cases because they can save much time and effort for a user. The following figure shows where these two commands are located.



Settings for WLAN Mobile Nodes

Several display flags are provided for WLAN mobile nodes in **Menu -> N_Setting -> 802.11(b) Wireless Network**.

Show Moving Path

This command can change a flag to display or not to display the moving paths of WLAN mobile nodes.

Show Icon

This command can change a flag to display or not to display the mobile node icons. It is useful when the user just wants to see mobile nodes' current locations (represented by boxes with solid and thick edges) and does not want them to be messed up with their initial locations (represented by mobile node icons). Not showing the initial locations of mobile nodes in the working area can make the current network topology clearer.

Show ID

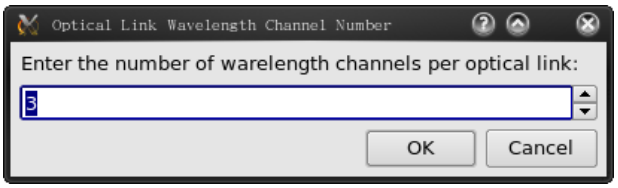
This command can change a flag to display or not to display the IDs of mobile nodes. Like other display flags, in a large simulation case, not showing the IDs of mobile nodes may make the current network topology clearer.

Settings for Optical Networks

The following commands can be executed to change the settings of optical networks. They are located in **Menu -> N_Setting -> Optical Network**.

Set Optical Link Wavelength Channel Number

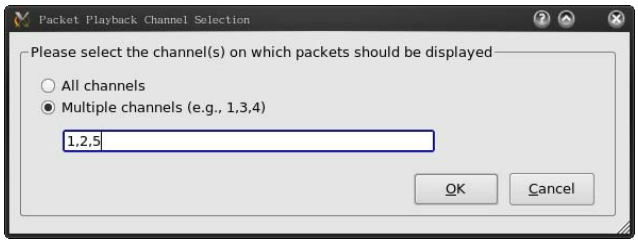
In a WDM optical network, an optical link usually have multiple channels using different wavelengths. In NCTUns, all optical links in a WDM optical network must have the same number of channels. This command sets the number of channels per optical link. The default number is 3. If a user wants to use a different number, he (she) must execute this command to change the setting before adding any optical link to the topology editor. Executing this command after an optical link is added is not allowed.



Set Optical Link Packet Playback Channel(s)

Like a packet transfer animation played on a fixed network, packets transmitted on an optical network can be played to show their movements on optical links. Since a WDM optical link has multiple channels and a user may be inter-

ested in seeing packets flowing on only one, several, or all channels of a link, this command is provided for a user to select which channels' packets should be displayed.



Set Optical Link Packet Playback Color

Like the channel color settings for packet playback on WLAN and GPRS networks, this command is provided to set the color scheme for packet playback over different channels of a WDM optical link.

Set Maximum OBS Control Packet Processing Time

The usage of this parameter for optical-burst-switching networks will be explained in a later chapter about optical networks.

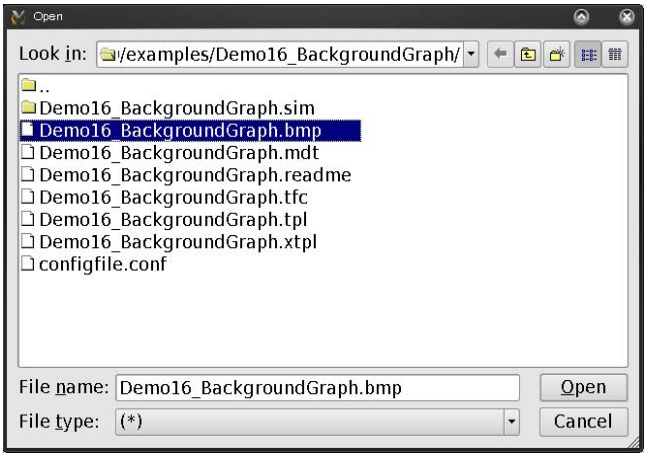
Setting the Background Graph

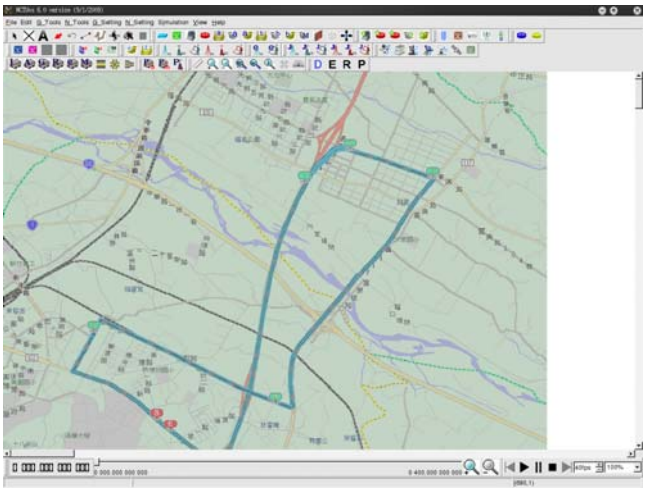
Sometimes placing a background graph on the network topology working area can provide a great value. For example, when a user studies how to place wireless access points or base stations in a city to achieve the optimal performance/utilization/coverage, it is much better if the user can place the city map on the working area as the background graph. Commands related to the background graph function are located in **Menu -> G_Setting -> Background Graph**.

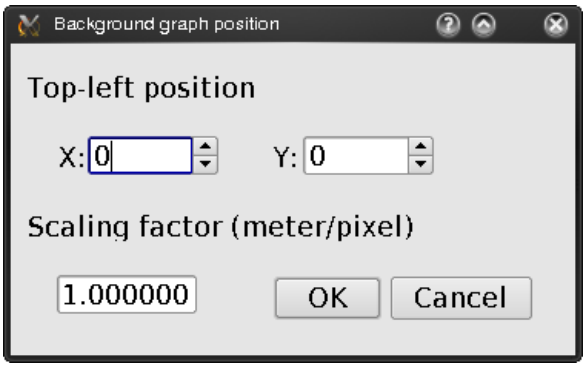
Paste Background Graph

This command selects a .bmp file and pastes it as the background graph.

In the following, we use an ITS (Intelligent Transportation Systems) simulation case as an example and paste a map of the HsinChu city in Taiwan on the working area.







Position Background Graph

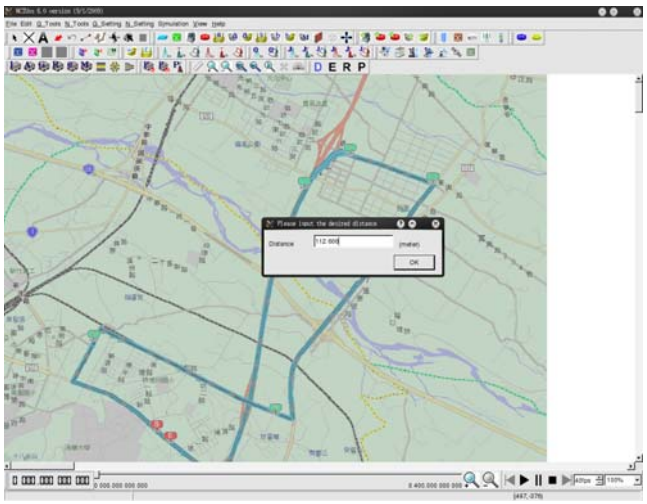
After pasting the background graph, the user can place the graph at any place (i.e., shift its top-left corner by an offset vector) on the working area and specify its scaling factor (i.e., enlarge it or shrink it).

Scale Background Graph

This command can scale the background graph in a different way. Sometimes it is more convenient than the scaling function provided in the dialog box of the above "Position Background Graph" command.

After executing this command, the user will automatically enter the "**background graph scaling**" mode. In this mode, like using the ruler function, the user can drag and drop the mouse over a line. A dialog box will pop up asking the user how long (in meters) the line corresponds to in the real world.

For example, on the bottom-right corner of the map there is a scale saying that this small segment corresponds to 891 meters in the real world. With this information, the user can drag and drop the mouse over this segment and input 891 into the dialog box. Usually after scaling the map to get the 1:1 ratio, the background graph will become very huge and thus only a very small part of it can be shown on the screen. The user can use the "view the whole field" tool button to view the whole background graph.

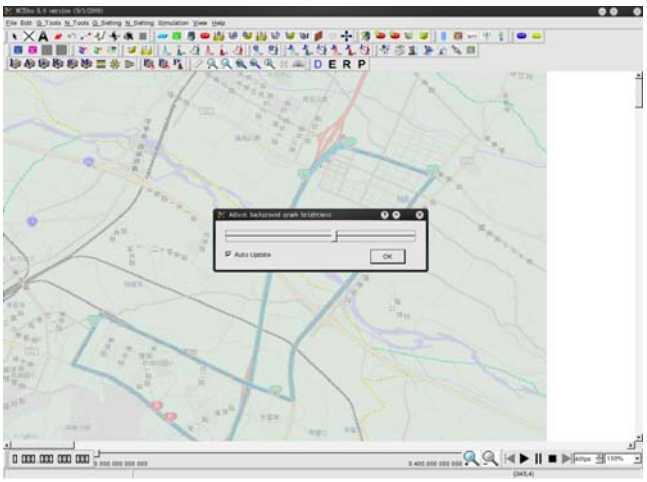


Set Background Graph Brightness

Normally the user will place the icons of network nodes on top of the background graph. To achieve a better visual quality, it is better to brighten the background graph a bit. This command allows the user to adjust the brightness of the background graph in a fine-grain way.

After a series of operations, now the background graph is properly set. When a user saves a simulation case, the current background graph settings will be saved to the file as well. Therefore, next time when the user re-opens the simulation case file (.tpl), the background graph will automatically be set up without the user's help.

Import Mobile Nodes and Their Paths from File



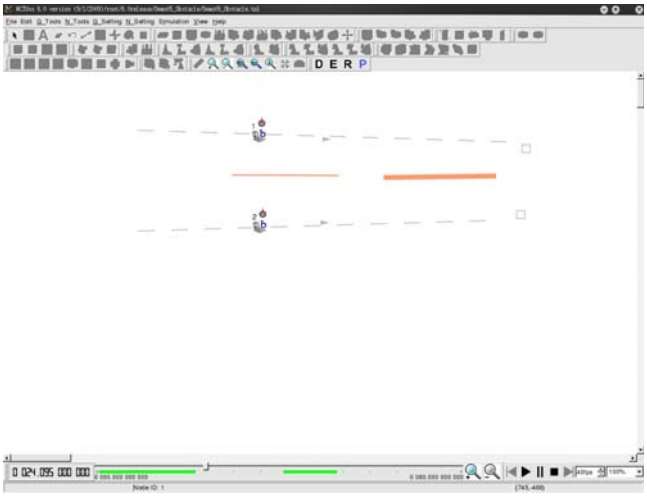
Using an ITS (Intelligent Transportation System) case as an example, now the user can import mobile nodes and their moving paths from a file. In this ITS case, each mobile node represents a mobile car and its moving path represents how it moves on the roads. This command is located in **Menu -> G_Tools.**

Import Network Traffic Application File

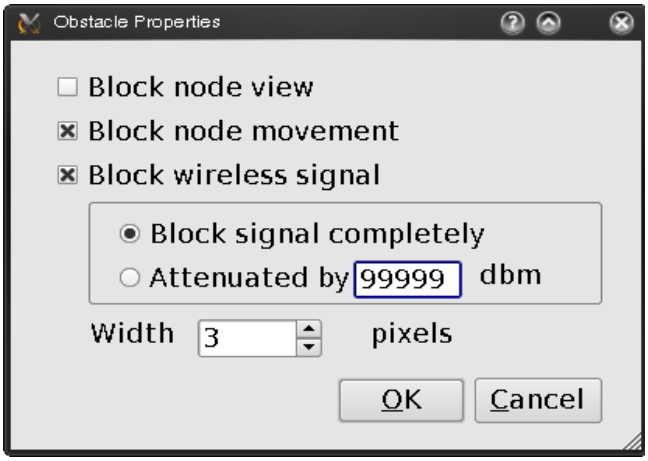
Suppose that we would like to run some application programs on these imported mobile cars to exchange information among them, we can use this command to import application program command strings from a .tfc file. The details of this command have been explained before. Executing this command can save the user a lot of time because he (she) need not invoke the GUI dialog box of every mobile car to specify their application programs. This command is located in **Menu -> G_Tools.**

Obstacles

In the real world, not all fields are open space for wireless signal. Some may have high mountains or tall buildings blocking wireless signal's propagation or attenuating their power. In some researches, we may want to purposely add obstacles to the open field to block/attenuate wireless signal at some places in the field. In NCTUns, an obstacle  is a rectangle that can block a mobile node's view, block a mobile node's movement, or completely block wireless signal or just attenuate the power of wireless signal. These properties are important for simulating tactical mobile ad hoc networks. An obstacle can be added in the same way like adding an arrow. With obstacles, a user can simulate a more complicated and interesting field setting. This can facilitate testing wireless network and protocol performances (e.g., handoff) under a more realistic field setting.



Communication between the two mobile nodes is affected by the obstacle located in the middle of them.



An obstacle can block node's view, node's movement, or wireless signal. Wireless signal can just be attenuated rather than being totally blocked.

Note that the single-hop connectivity and multi-hop connectivity calculations provided in a mobile node's dialog box take into account the existence of obstacles. In addition, the God routing daemon for WLAN ad-hoc mode mobile nodes takes into account the existence of obstacles as well. The name of the file that describes the obstacles in a simulation case is XXX.obs.

If a user clicks and holds on one side of an obstacle, a yellow square box will appear at that side and he (she) can rotate or extend the obstacle. Another side of the obstacle is the fixed point of the rotation or extension operations. If a user clicks on the middle part of an obstacle, a yellow square box will appear at both sides and he (she) can move the selected obstacle to any place.

If a user double-clicks an obstacle, a property dialog box will pop up. A user can specify the obstacle's properties such as its width, whether it should block mobile nodes' view, whether it should block mobile nodes' movement, and whether it should block wireless signal or just attenuate the power of the signal.

Sometimes a user may want all obstacles to have the same property that is different from the default property. It is tedious to change the property of each obstacle one by one after every obstacle is placed. Therefore, a user is suggested to change the default property of an obstacle before placing any obstacle by using the **Menu -> G_Setting -> Obstacle** command. After this operation, all obstacles added will have the new default property. If the user needs to place more obstacles with different property, he (she) can use the above command again to change the default property of an obstacle.

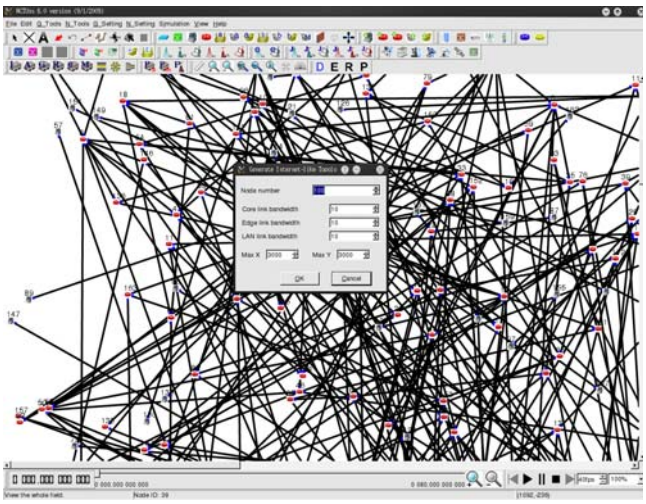
Generate Large Networks

To generate a large network topology, it is tedious for a network researcher to add nodes and links to the topology editor one at a time. NCTUns provides a convenient tool for a user to automatically generate a large network whose structure is similar to that of the Internet. A user can execute the **Menu -> G_Tools -> Generate Large Internet-like Network** command to specify the parameters of the large network to be generated.

In the parameter dialog box, the "Node Number" field specifies the number of nodes of the network to be generated. This number cannot be too small. Otherwise, the generated topology will not share the same properties with the Internet topology. Links in the generated network are classified into three different categories and each category can use a different bandwidth. These categories are the core, edge, and LAN links, respectively. The unit of bandwidth in this dialog box is Mbps.

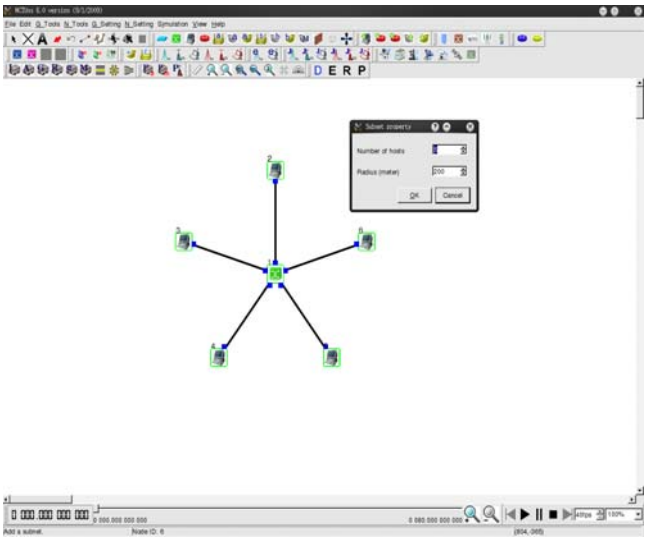
The "Max X" and "Max Y" fields specify the length and width of the field over which the generated network will be laid. Their default values are taken from the simulation case's field sizes, which can be configured in **Menu -> G_Setting -> Simulation.** Each node in the generated topology will be placed on the field according to their generated (x, y) locations. The signal propagation delay of a

link between two nodes will be automatically calculated and set. It is the distance between these two nodes divided by the light speed.



Subnet

To quickly expand a simple network topology, a user can choose the subnet  function on the tool bar and then click on the working area to insert a group of hosts. The group of added hosts are all connected to a switch. When the subnet dialog box appears, a user can enter the desired number of hosts and the desired subnet radius. The following figure shows the subnet dialog box.



File manipulations

Several commands are provided to manipulate files. They are located in **Menu -> File**.

New

Executing this command will close the current simulation case and clear the working area for a new case.

Open

Reload an already existing case. The .tpl file of the desired case should be selected to open the case.

Save

Save the current simulation case's topology and node configurations into the .tpl and .tcl file, respectively. This case can later be reloaded.

Save as

Save the current simulation case's topology and node configurations into a new file suite. The name of the case shown on the screen is changed from the current case name to the new case name.

Print to File

Capture the network topology area shown on the screen and save it to a .bmp file. The captured graph can later be sent to a printer for printing or be included in a technical report for illustration.

Background Job Management

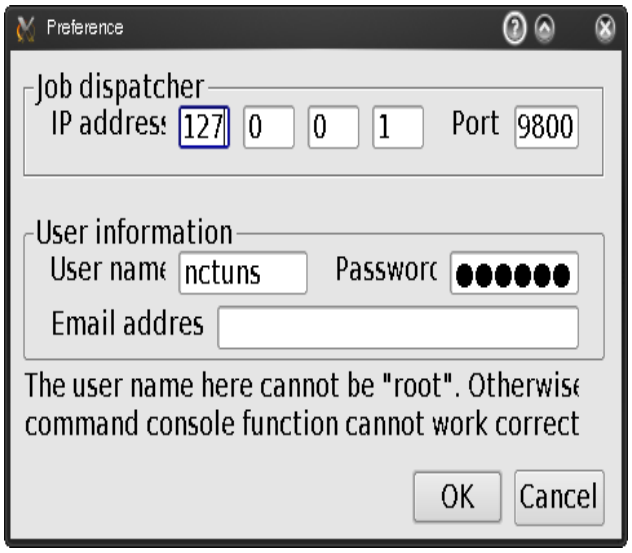
Any background job submitted to the dispatcher can be manipulated here. They can be deleted, stopped, aborted, or retrieved. The following figure shows the dialog box of this function.

The “Refresh” button is used to update the information shown in this table. Each time the user clicks this button, the GUI program will retrieve the most up-to-date information about each background job from the dispatcher.

Setting the Simulation

Dispatcher

The command for setting the dispatcher used for the current simulation case is located in **Menu-> G_Setting -> Dispatcher**.



This dialog box asks a user to provide the IP address and port number used by the dispatcher. The GUI user’s login account and password for using the remote (can be local) simulation server should also be provided here. It is **VERY** important that the account name of the GUI user used on the local GUI machine and that used on the remote (can be local) simulation server should be exactly the same. Otherwise, the network simulator cannot work correctly. For the single-machine mode, the user name specified here **MUST** be the same user account name by which the user logs into this local machine. Otherwise, the simulation cannot run correctly. For security concerns, the “root” account is not allowed and thus is blocked here by the GUI.

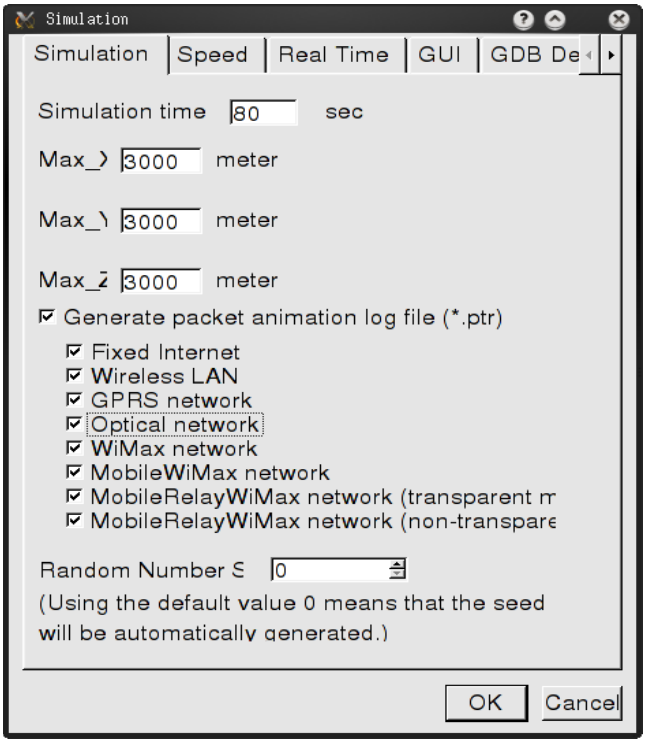
If the user is using the single-machine mode, the IP address entered here can be 127.0.0.1 (the IP address of the loopback interface lo0). The port number entered here must be the same as the CLIENT_PORT specified in the dispatcher.cfg

Simulation

The command for setting the various global parameters of the current simulation case is located in **Menu -> G_Setting -> Simulation.**

Under the **[Simulation]** tab, the total simulation time in virtual time and the maximum of X, Y, Z coordinates can be specified. Currently the maximum time that can be simulated is 4,200 seconds in virtual time. The user can select whether the .ptr file (packet transfer trace) should be generated or not. The user can further select which types of network’s packet transfers should be logged into the ptr file.

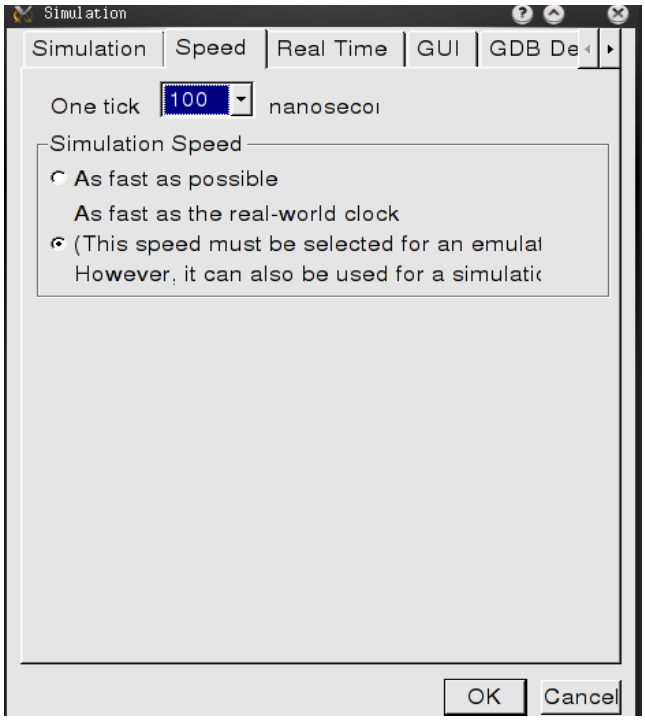
The random number seed given to the simulation engine for this simulation case can also be specified. Using the default value of 0 indicates to the simulation engine that it can choose a random number for the random number seed. That is, each time the same simulation case is run, a different random number seed will be used. If the random number seed is fixed to a value greater than 0, NCTUns can generate repeatable results for each run of the same simulation case.



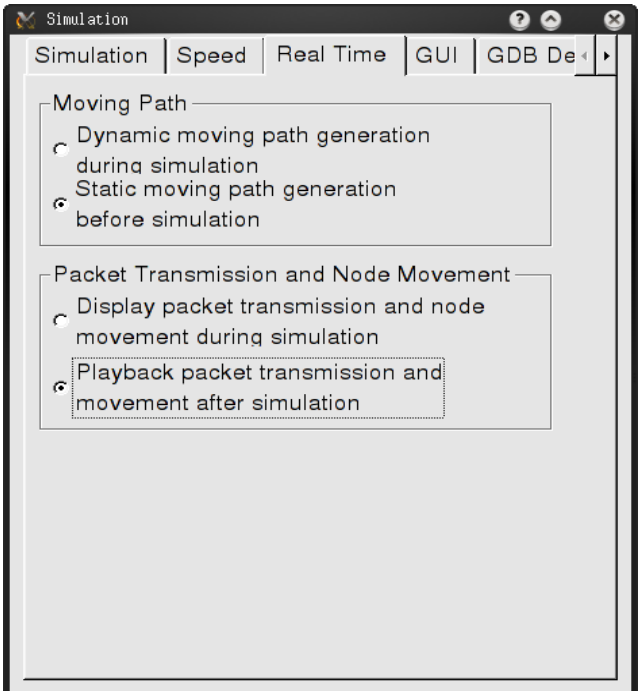
Under the **[Speed]** tab, the tick time can be specified. The default setting is that one tick represents 100 nanoseconds in virtual time in a simulation. This setting can be changed to a

smaller value such as 10, or 1 nanosecond, which is useful for generating more accurate results on high-speed networks (e.g., with more than 1 Gbps bandwidth links).

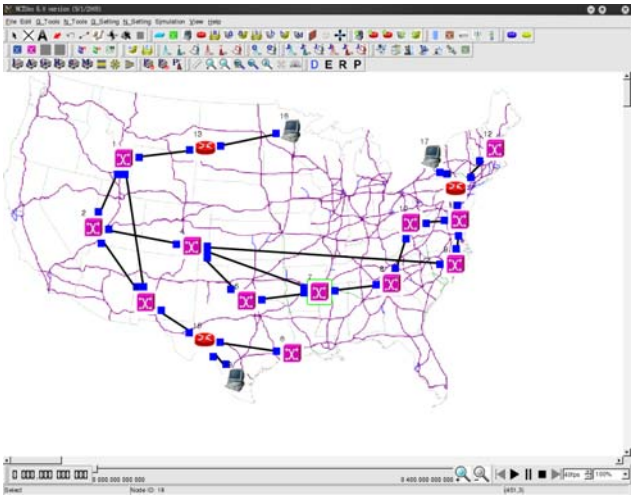
The speed of the simulation engine can be set to “As fast as possible” or “As fast as the real-world clock.” Normally, a user would want a simulation case to be finished as soon as possible. However, when NCTUns is turned into an emulator or the user conducts a human-in-the-loop tactical mobile ad hoc network simulation, the speed of the simulation engine should be set to “As fast as the real-world clock.” This option is also useful when a user wants to use the command console during a simulation. The following figure shows the dialog box of the speed tab.



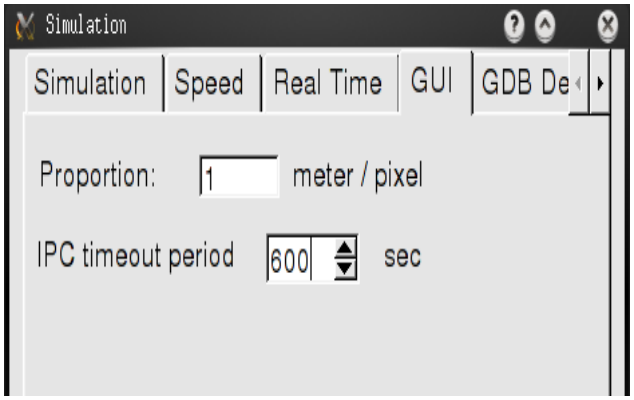
Under the **[Real Time]** tab, two GUI display options for military tactical mobile ad hoc network (MANET) simulation can be specified. In general MANET simulation cases, each mobile node's moving path is pre-specified before the simulation is started. In contrast, in military tactical MANET simulation cases or Intelligent Transportation Systems simulation cases mobile nodes' moving paths are dynamically generated by agent programs running on mobile nodes during simulation. To allow such type of simulations, the option “Dynamic moving path generation during simulation” must be chosen. In addition, if a user wants to see the display of packet transmission and node movement during a simulation, the option “Display packet transmission and node movement during simulation” has to be chosen.



Under the **[GUI]** tab, the ratio of meter/pixel can be specified. Changing this setting to a larger value (e.g., 100) is useful for a network whose size is physically very large (e.g., the backbone network of USA, see the following figure).



If a network is physically very large and nodes need to be placed at their correct positions on a map with the correct physical distances between them, it is better to use a larger value for the meter/pixel ratio parameter so that node icons can still be seen with the whole



Using a large value can allow the whole network to be clearly shown on the screen without using the "Zoom Out" function. Although the user can use the default value (i.e., 1) and the "Zoom Out" function to display the whole network topology on the screen, node icons will become too tiny to be seen on the screen and it will be very difficult for the user to manipulate these tiny icons (e.g., to select them).

Under the **[System command]** tab, to-be-executed system commands and their output file names can be specified here. A system command is a command that, when executed, will get or set an object's value at the specified time. The output of the command will be saved to the specified output file, which will later be transferred back to the GUI program when the simulation is finished.

In addition to getting/setting a single object's value, the values of all objects of the same kind can be get or set at the same time to take a global snapshot of the whole network. For example, this function can be used to take the snapshot of the current routing tables of all routers. This global snapshot information can help a researcher study the convergence of a protocol.

Time: the starting time for executing this command

Command: the system command string

Output file name: the name of the output file

The system commands provided by NCTUns are listed below. Their syntax and meanings are also explained below.

Set: set a value to a variable in a module

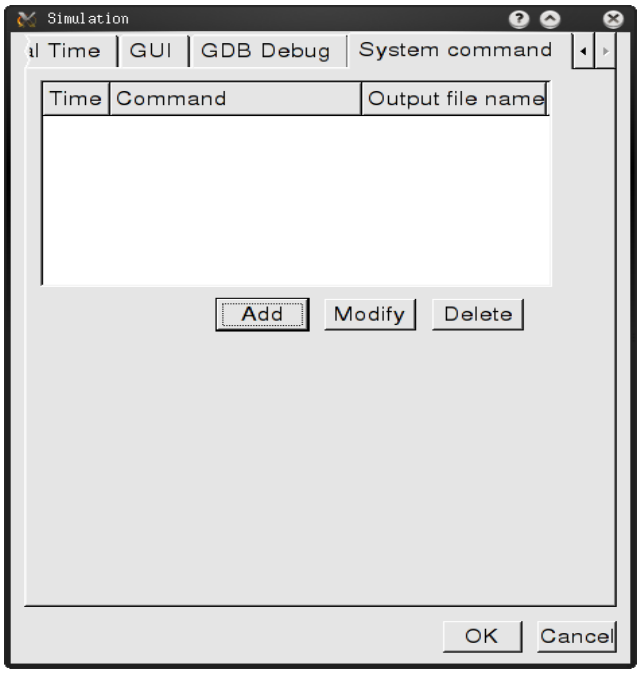
Set {node} {port} {module} {tag} {value}

Get: get the value of a variable from a module

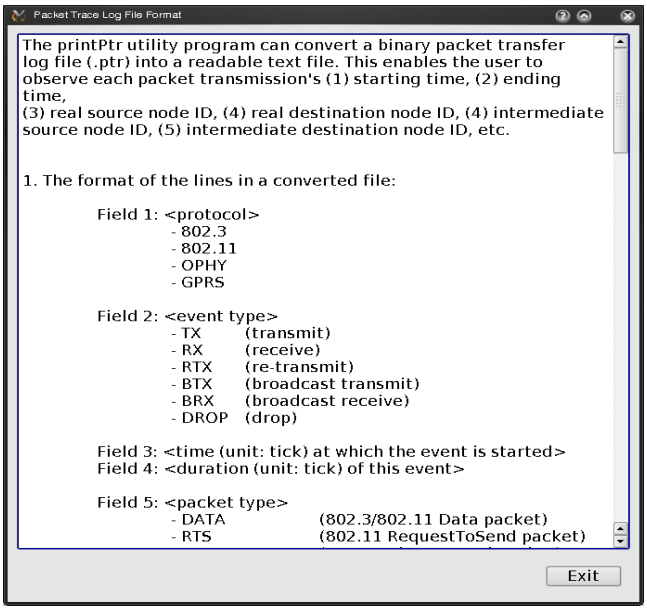
Get {node} {port} {module} {tag}

GetAll: like Get, but get the values of the requested variable from the same modules used in all ports of all nodes

GetAll {module} {tag}



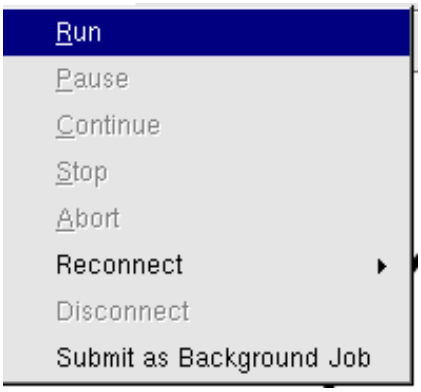
Note that a tag is a string associated with a particular variable declared and used in a protocol module. A variable here can be a single-value variable (e.g., a FIFO queue's maximum queue length) or a multi-column multi-row table (e.g., a switch table that has multiple [IP address, MAC address] mapping entries). It is the protocol module developer's job to write a command() method in his (her) module to recognize a tag and then get/set the value of its associated variable.



More information about the get/set command can be found in “The Protocol Developer Manual.for the NCTUns 6.0 Network Simulator and Emulator”

Running the simulation

Several commands are provided to control the execution of simulation cases. They are located in **Menu -> Simulation**.



Run, Pause, Continue, Stop, Abort

After a user switches to the “Run Simulation” mode, the user can start running the simulation by executing the “Run” command in this group.

During simulation, the user can use the “Pause,” “Continue,” “Stop,” and “Abort” commands to pause, continue, stop, and abort the simulation. The difference between the “Stop” and “Abort” commands is that the former command will return the current simulation results to the GUI program while the latter command will not.

Reconnect, Disconnect

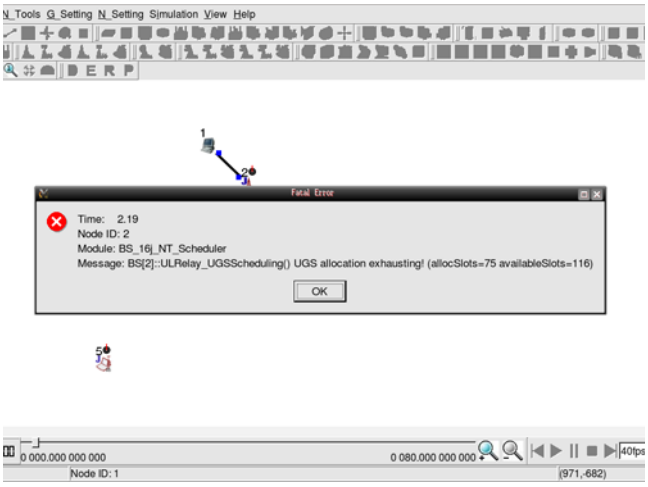
A user can disconnect the GUI from a currently-running simulation job. Doing this allows him (her) to quit the GUI program and switch to do other things. The user can come back later, restart the GUI program, and then reconnect to the disconnected simulation job.

Submit as Background Job

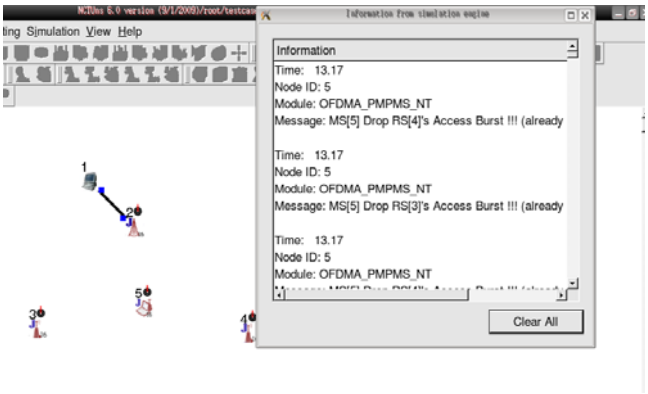
A user can directly submit a simulation job as a background job to the dispatcher for execution. Its effect is the same as first running up the simulation and then immediately disconnecting the GUI from the just launched simulation job. To reconnect to a currently running background job or retrieve results from a finished background job, the user should use the **Menu -> File -> Background Job Management** command.

View Messages from Simulation Engine

NCTUns provides a runtime messaging mechanism to enable protocol modules to dynamically send messages to the GUI program during simulation. In the Run Simulation mode, when the GUI program receives a message from a protocol module, it will pop up a window to show the received message. The following figure shows a snapshot of the popped-up window.



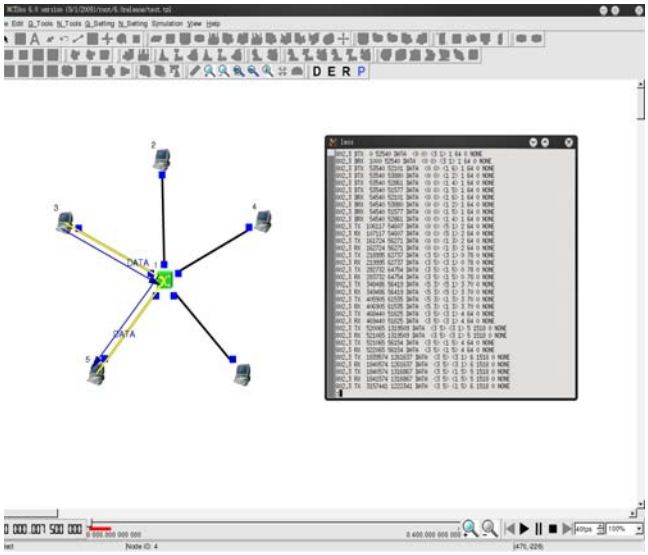
After the simulation is completed, one can use the command “**Menu -> G_Tools -> View Messages from Simulation Engine**” to review the messages issued by protocol modules in the Play Back mode. The snapshot of this tool is shown below.



To dynamically transmit messages to the GUI program, a protocol module has to use specific message-passing APIs provided by the simulation engine instead of using traditional message-printing library calls, such as printf(). More information about these APIs is explained in the “The Protocol Developer Manual for the NCTUns 6.0 Network Simulator and Emulator.”

View Packet Trace

It is useful to view the packet trace file in a human understandable way. Viewing this file can help a researcher debug a network or a protocol. To do so, a user can execute **Menu -> G_Tools -> View Packet Trace** to open the desired .ptr file. The binary .ptr file will be converted to text by the "printPtr" tool automatically and shown in the popped up window. The text is shown by the "more" program, which supports vi-like search commands.

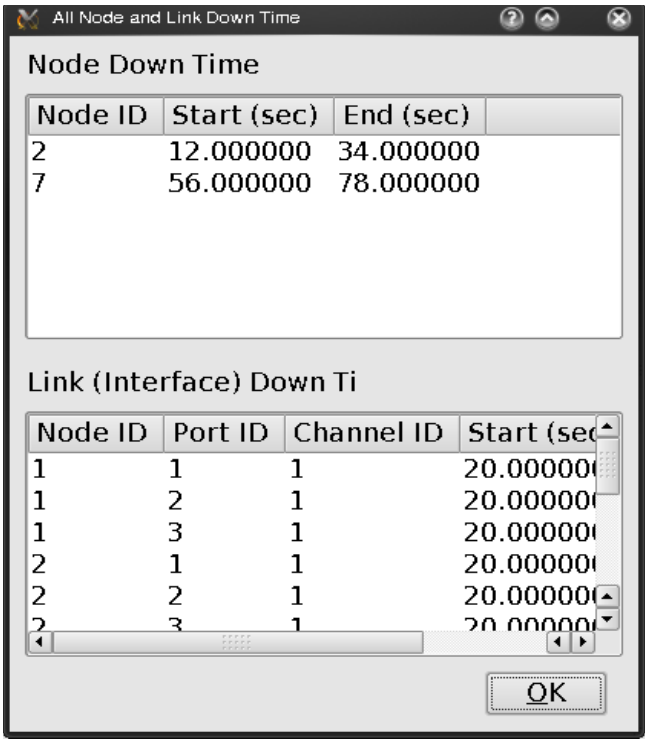


Show Packet Trace Format

This **Menu -> G_Tools -> Show Packet Trace Format** command shows and explains the format of the output generated by the **Menu -> G_Tools -> View Packet Trace** command. The following figure shows the result of executing this command.

Display All Node and Link Down Time

A user may set down times for nodes and links to test how network protocols would respond to these down times. For WDM optical links, down times can also be set for each individual WDM channel. This **Menu -> G_Tools -> Display All Node and Link Down Times** command displays the down times specified for all nodes and links in the simulated network. A user can execute this command to have a global view of the down times specified for the whole simulated network.



Set the Frequency of Updating Mobile Node Routing Paths (for the GOD Module)

This **Menu -> G_Tools -> Set the Frequency of Updating Mobile Node Routing Paths (for the God Module)** command controls how frequently the routing paths should be recomputed for the GOD routing module. A higher frequency allows the GOD routing module to respond to link failures more quickly but at the cost of generating a larger file to store more information.

Summary

The topology editor provides users with a friendly and easy-to-use working environment. In this environment, a user can quickly build network topologies and specify application programs. Executing and controlling simulations can also be easily done in this environment.

4. Node Editor

The node editor provides a convenient environment for a user to flexibly configure the protocol modules used inside a network node. By using this tool, a user can easily add, delete, or replace a module with his (her) own module to test the performance of a new protocol.

Protocol Module Concept

A protocol module implements a particular protocol such as ARP or a particular function such as the FIFO packet scheduling discipline. In the node editor, all modules that are grouped in the same module group (displayed at the top of the node editor) share similar properties. For example, in the 802.11 MAC group, we may have one module called “802.11MAC” while having another one called “my802.11MAC.”

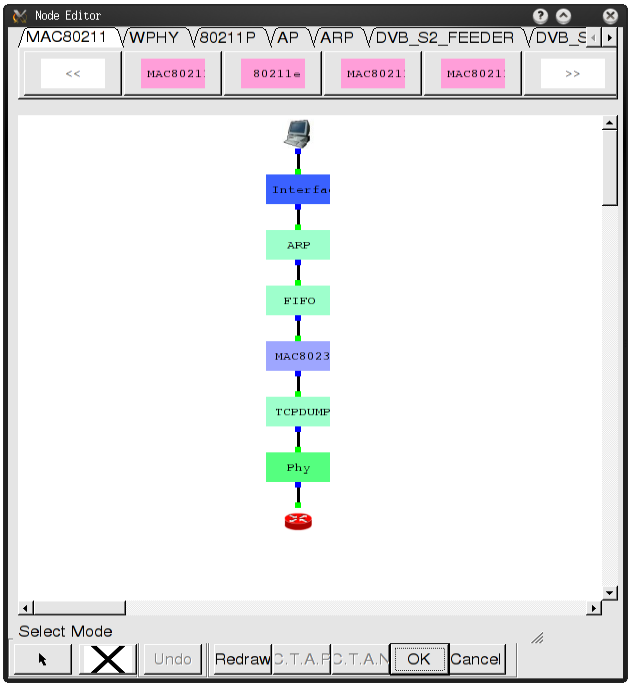
NCTUns provides several pre-developed protocol modules. Users can add new protocol modules to the node editor or replace some existing modules with his (her) own ones. For example, in the PSBM (packet scheduling and buffer management) module group, four modules (FIFO, Random-Early-Detection, Deficit-Round-Robin, WAN) are currently supported. A user may add a new PSBM module such as a RIO module to it.

Detailed information on how to add a new protocol module to both the simulation engine and the node editor is documented in “The Protocol Developer Manual for the NCTUns 6.0 Network Simulator and Emulator.”

Screen Layout Explanation

In the following, we will briefly explain the screen layout of the node editor. To see the node editor, in the topology editor a user first switches the mode to the “Edit Property” mode by executing the **Menu -> File -> Operating Mode -> Edit Property** command. Then the user can double-click a node that he (she) wants to edit. After the node’s dialog box shows up, the user can click the “Node editor” button to invoke the node editor to edit that node’s protocol stack.

At the top of the node editor are various module groups. The protocol modules that share the same role in a protocol stack are grouped together under the same group name. When the user clicks one module group button, all modules belonging to that module group will be shown right below the module



The node editor’s screen layout.

group buttons. Because only four modules can be shown at the same time, the user can use the “<<” and “>>” buttons to see other modules not shown on the screen.

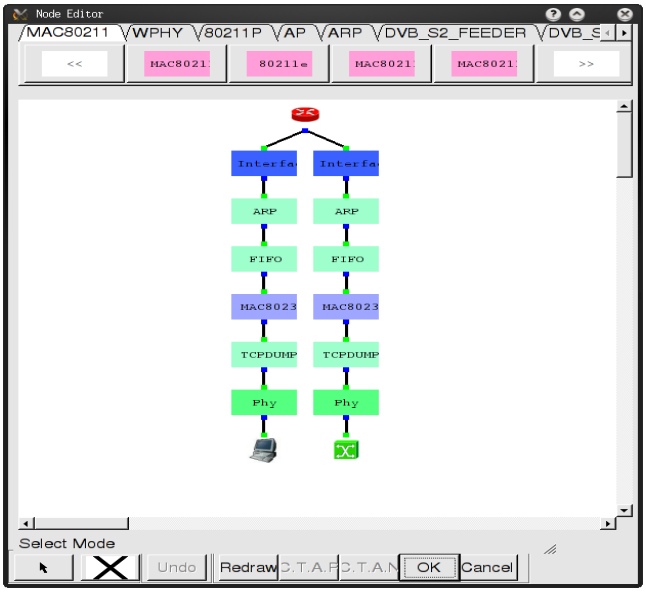
In the middle working area, the protocol modules used by this node are shown. Here, a chain of protocol modules represent the protocol stack used by a port (interface). The user can use the mouse to easily add, delete, or replace protocol modules in the working area.

At the bottom are several control buttons. The “Cancel” button discards all changes that have been made to this node’s protocol modules. The “OK” button accepts all of the changes made so far. The “Undo” button removes the effect of the last delete operation. (Note: only the **LAST** delete operation can be undone.) The “Redraw” button re-layouts the protocol modules so that they look nice when shown on the screen. (This is particular useful after a user performs the insert or delete operation.)

The Copy-To-All-Port (CTAP) button copies the values of the currently selected module’s parameters to the same modules in all ports of this node The Copy-To-All-Node (CTAN) button does the similar job. However, it copies the values to the same modules in all ports of all nodes in the whole simulated network.

The "**X**" button means "delete." After clicking this button, now the node editor's mode enters the "delete" mode. From now on, whenever the user uses the mouse to left-click a module or a link, that object will be deleted. The "Arrow" button means "select." After clicking this button, now the node editor's mode enters the "select" mode. From now on, the user can move a protocol module to any desired place. The user can also choose a module from a module group, insert, and place it in the middle working area.

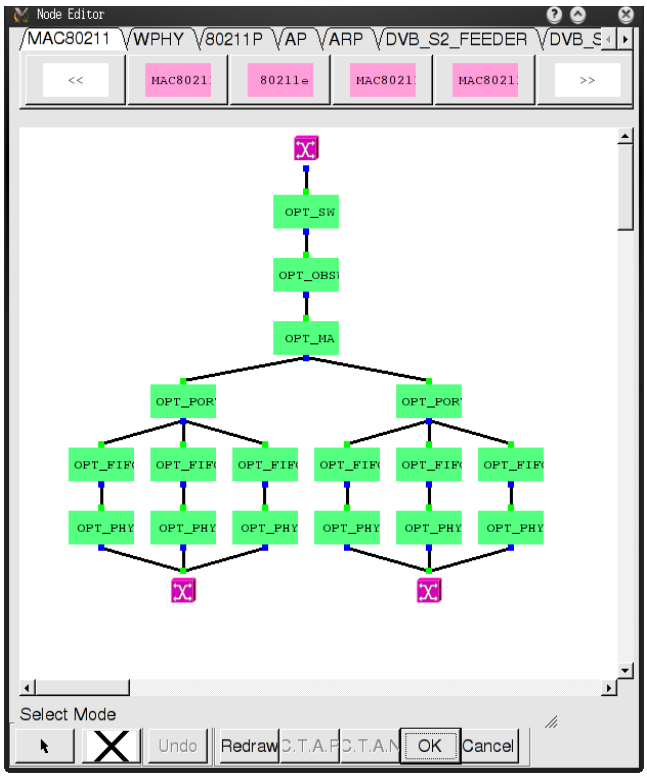
In the node editor, a chain of protocol modules represents the protocol stack used for an interface. As such, if a router has two interfaces, it will have two module chains. For example, if a router has one interface that connects it to a host and has another interface that connects it to a switch, it will have two protocol chains shown in its node editor. The following figure shows the node editor for this router.



To help a user distinguishes which module chain is for which interface, the icon of the remote node that an interface connects to (through a link) is shown at the bottom of that interface. As such, in the figure, a green switch icon and a grey host icon are placed at the bottoms of the two interfaces, respectively.

If the remote nodes that a node connects to are all of the same type (e.g., suppose that in the above example the router connects to two hosts), showing the remote nodes' icons at the bottom does not help distinguish interfaces. In this case, the user can position the mouse cursor over a remote node icon in the node editor. The node ID of the selected remote node and the ID of the port on that remote node which connects to this node will be shown at the bottom of the node editor. This information can help the user distinguish interfaces when remote nodes are of the same type.

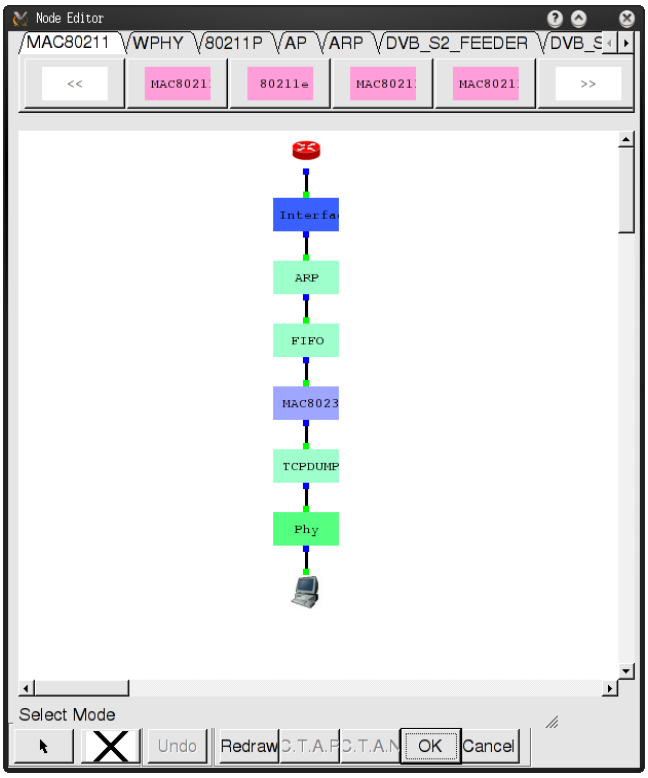
The protocol stacks of a node can have two levels. In WDM optical network simulations, not just each interface needs a protocol stack; instead, each WDM channel of an interface needs a protocol stack. Therefore, a two-level protocol stack may be displayed in the node editor for WDM nodes. The protocol modules at the first level are relevant to an interface while the protocol modules at the second level under an interface are relevant to a WDM channel of that interface. The following figure shows an example.



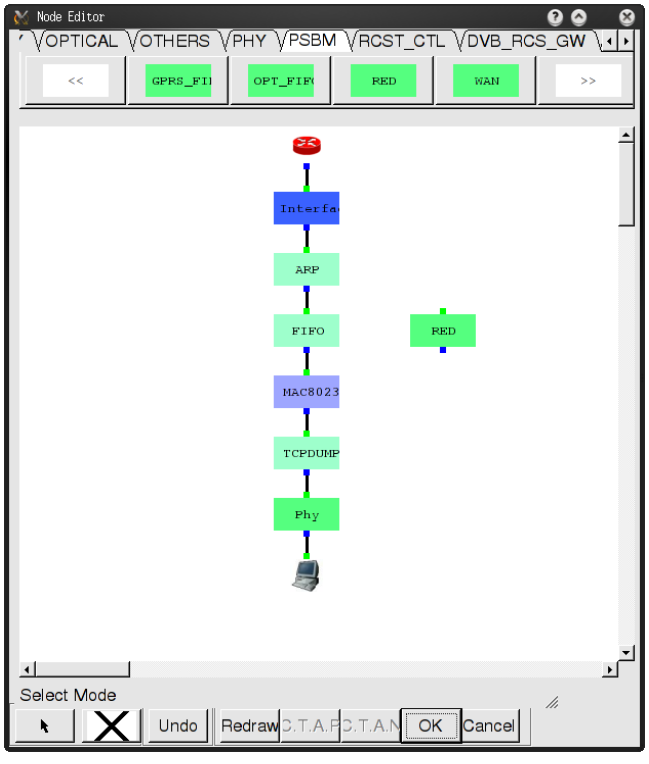
Add, Delete, and Replace a Module

Here we use an example to illustrate how to replace a FIFO module with a RED module.

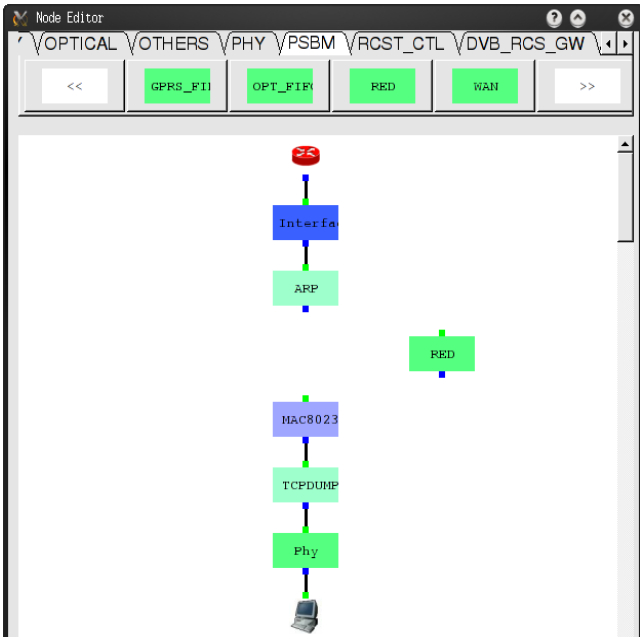
Step 1: We first invoke the node editor of a router so that its initial protocol module chain is shown as follows.



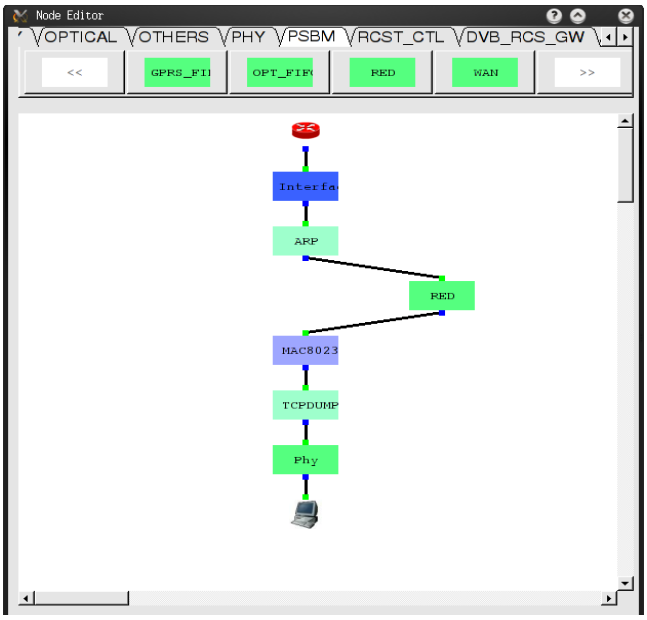
Step 2: Then we choose the RED module from the top and place it in the middle working area. The resulting screen is shown below.



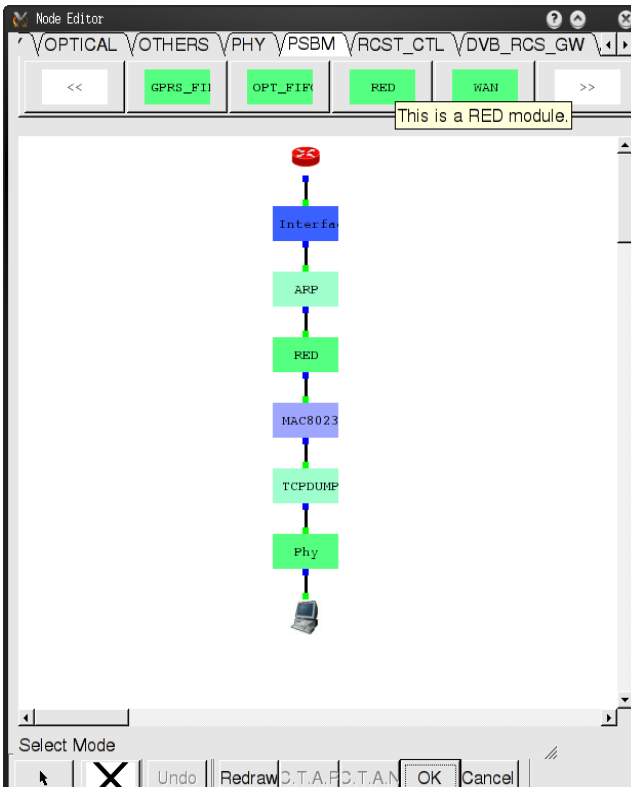
Step 3: Then we select the "X" tool button and click the mouse on the FIFO module to delete it. The result is shown below.



Step 4: Then we link the RED module with the ARP and MAC802.3 modules together. To link together two modules, a user performs the same operation as he (she) does when creating a link between two nodes in the topology editor. At the top and bottom of a module, there is a small box. A link must start and end on these small boxes. After linking up these modules, the result is shown below.



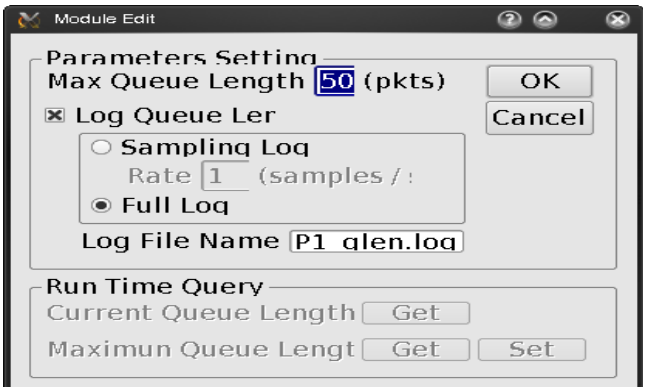
Step 5. Since the job is finished, now we redraw the node editor to make it look beautiful. The result is shown below.



Step 6. If we would like to keep the changes made so far, we can click the "OK" button. On the other hand, if we would like to discard all changes that we have made so far, we can click the "Cancel" button.

Set or View Module Parameter Values

To set or view the values of a module's parameters, a user can double-click a module in the middle working area and then its module parameter dialog box will appear. The following figure shows the parameter dialog box of the FIFO module.



Add a New Module to the NCTUns

After a user has developed his (her) own module, two tasks must be done to integrate the new module into the NCTUns. The first task is to introduce the new module to the node editor so that it can appear in an appropriate module group and its parameter dialog box can be shown when it is double-clicked in the middle working area. The second task is to register the new module with the simulation engine so that its code is executed when a simulation case using the new module is executed.

Add a New Module to the Node Editor

To let the node editor know that a new module has been added to it, the user must add and place the definition of the module into the module description file (mdf.cfg). To understand the detailed format and meanings of the module description file, readers should refer to that file stored in /usr/local/nctuns/etc and "The Protocol Developer Manual for the NCTUns 6.0 Network Simulator and Emulator."

Register a New Module with the Simulation Engine

To let the simulation engine find the code of the new module and successfully execute it, the user must also register the module code with the simulation engine.

NCTUns provides a simple method for a user to register a new module with the simulation engine. Detailed procedures are documented in the "The Protocol Developer Manual for the NCTUns 6.0 Network Simulator and Emulator."

Summary

In this chapter, we present the concept of protocol modules and the node editor. The node editor is an environment in which a user can flexibly configure the protocol stack and parameter values used inside a node. NCTUns provides some pre-built protocol modules. A user can easily add his (her) own protocol module to the node editor to test its performance.

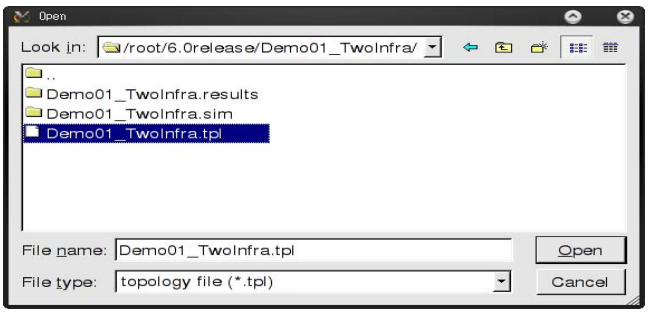
5. Packet Animation Player

After a simulation execution is finished, the generated simulation results will be automatically transferred back to the GUI program and then saved in the user's local hard disk. Suppose that the simulation case's topology file is named "test.tpl." Then the name of the resulting packet animation trace file will be "test.ptr." Later on, when the user wants to do post analyses about the simulation results, he (she) can use the "Packet Animation player" to play back the animation. This is a very useful feature for both education and research purposes.

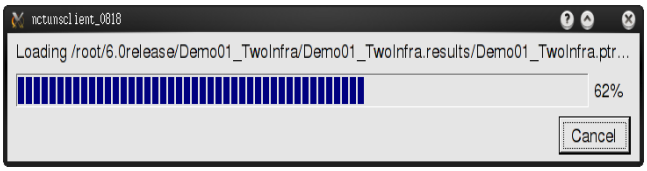
Reloading Simulation Results

To watch a previously generated packet animation trace, a user should first open its corresponding topology file.

Menu -> File -> Open



The user then switches to the "Play Back" mode directly. The GUI program will then automatically reload the simulation results (including the packet animation trace file). Since the animation file is usually very large, this process may take a while. To give the user an idea of the progress, a progress bar is shown during the loading process.



After the packet animation trace file is loaded, the user can left-click the start button (▶) of the time bar located at the bottom. The player will start playing back the logged packet transfer animation.

General Options for Packet Animation

During the play of a packet animation trace, a user can change some options of the GUI program to suit his (her) needs. These options are described below.

Time Bar

The time bar shows the packet animation progress in a time interval, which is called a time window here. A user can drag the time knot to any desired time. Two buttons are provided to change the size of the time window by a factor of 10. That is, the time window size can be either increased 10 times larger or decreased 10 times smaller. A user can conveniently perform this job by left-clicking the "zoom-out" button ( ) or the "zoom-in" ( ) button.

Time bar and its knot

Right below the time bar, a red vertical line indicates that a wired packet transmission starts at this time, a green vertical line indicates that a wireless LAN packet transmission starts at this time, and a blue vertical line indicates that a GPRS packet transmission starts at this time. Note that because the ending times of packet transmissions are not depicted here, it may be difficult for a user to move the time knot to the time when a packet transmission exactly ends. Therefore, these vertical lines are depicted here for reference purposes only. The GUI program purposely ignores WLAN broadcast packets and does not plot vertical bars for them on the time bar. This is because a WLAN access point broadcast its beacon frame every 0.1 seconds and plotting these broadcast packets on the time bar will de-focus the user's attention on important packets generated by application programs.

To know exactly when a packet transmission starts and ends, a user can use the printPtr utility program to first convert the binary animation trace file into a text file and then search it in the file.

Animation playing buttons

Animation playing buttons are provided to alter playing sequences. They can be executed by left-clicking their corresponding buttons.

(▶) plays the animation. If a user clicks it while the animation player is idle, the player will start to play the packet animation trace. If a user clicks it while the animation player is already running, the time knot will jump directly to the nearest future time where there is a packet transmission. This feature is very useful when the traffic is sparse.

(⏸) pauses the animation.

(■) stops the animation.

(|◀) moves the animation time window by one time window size in the backward direction.

(▶|) moves the animation time window by one time window size in the forward direction.

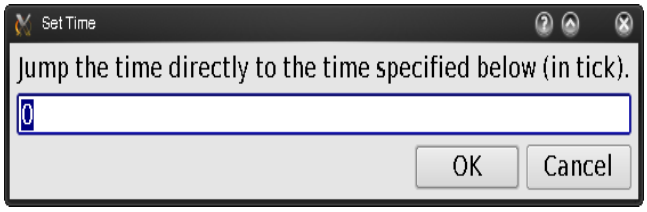
The 40fps (frames-per-sec) selection box controls the display quality of the animation. It defines how many frames should be played in a second in the real time. Using a smaller value can increase the animation speed because fewer CPU cycles are needed to refresh the screen. However, the resulting animation may become rigid and not smooth.

The 100% selection box controls the progress of the animation. It affects the time advancement quantity of the playback clock. During playback, the playback clock is advanced by a fixed time quantum in each of the playback loop. After the playback clock is advanced, all of the packet transfers whose transmission period (i.e., the period between the transmitting and receiving times) covers the current playback clock time are selected to be displayed on the screen. Choosing a larger value for this parameter will advance the progress of the animation playback more quickly. However, more packet transfers will be skipped and not displayed in the animation playback. Therefore, if packet transmission times over the links in a simulated network are tiny (e.g., tiny 58-byte TCP ACK packets transmitted on a 10 Mbps link or 1500-byte TCP data packets transmitted on a 1 Gbps link), it is better to use a smaller value for this parameter to see them.

The default value for this parameter is 100%. Other values such as 200% and 50% are provided. If the ratio of the selected value to the default value is X, the used time advancement quantity will be X times of the default time quantity.

If the playback clock is not advancing, the time knot can be dragged to any location to jump directly to a desired time. The following figure shows the time bar.

If the user knows the exact time where the playback clock should directly jump to, he (she) can double-click the clock display area at the left to enter the time. The unit of the entered time should be in tick and the relationship between a tick and its duration in virtual time is specified in **Menu -> G_Setting -> Simulation's [Speed]** tab. This function is particularly useful when the user has used the "printPtr" utility program to read the ptr packet trace file and wants to jump the clock directly to a specific time to see the packet transfer activities occurring at that moment. The following shows the dialog box of this function.

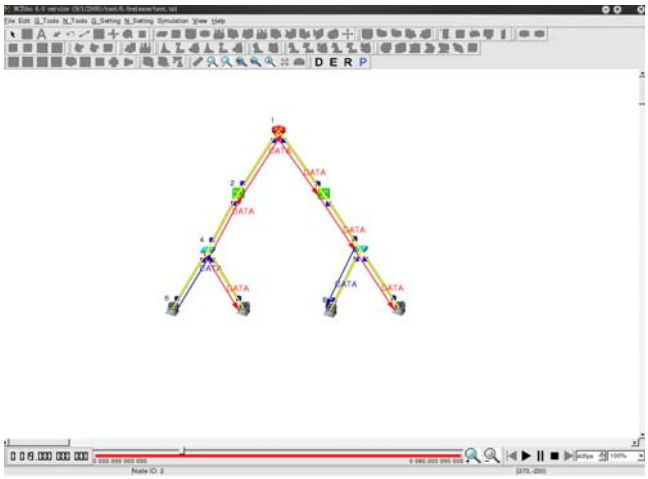


Animation Effects

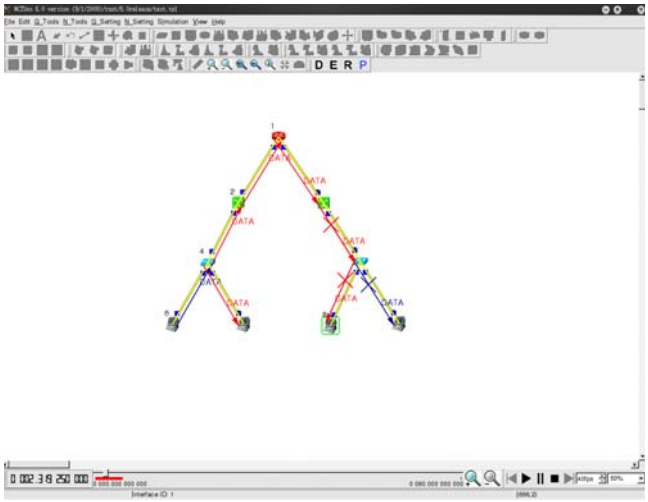
Wired network and wireless network have different characteristics. Therefore, we demonstrate their corresponding animation effects separately.

Wired Network

We use two screen shots to illustrate and explain wired network packet animation.



Successful packet transmissions

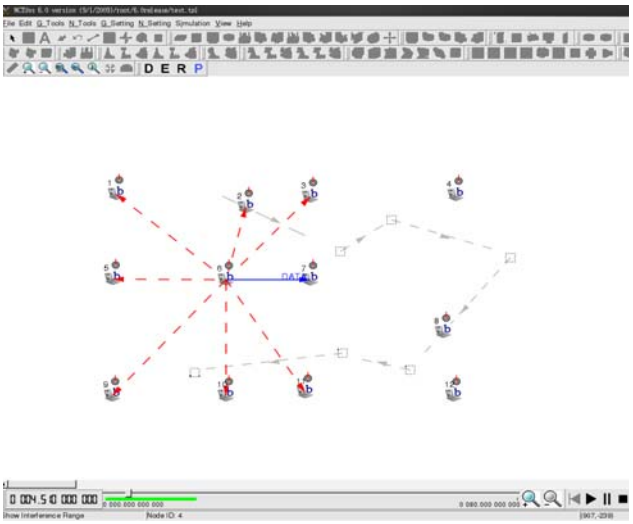


Packet drop & collision (represented by cross)

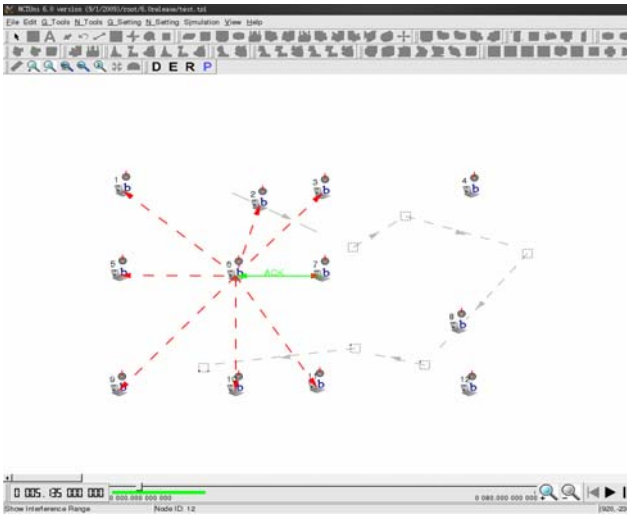
- A link is painted in yellow color if there is any packet flowing on it.
- A packet is depicted by a segment with an arrow (for brevity, it will be called an “arrow” in the following description.).
- A collided packet is depicted by an arrow with a cross on it.
- During a packet transfer, if a link is painted in red, it means that this link is an intermediate link for this packet. In contrast, if this link is painted in yellow, it means that one end of this link is the real source or destination node of the packet.
- The arrow length is determined by the packet’s length. Therefore, a user can expect that the arrow length is proportional to the packet length. In fact, a packet’s segment length on a particular link is determined by the transmission time of that packet on that link relative to the signal propagation delay of the link.

Wireless LAN Network

Similarly, in the following, two screen shots are presented to illustrate and explain the wireless animation effects.



Wireless packet transmissions (IEEE 802.11 DATA frame)



Wireless transmission (IEEE 802.11 ACK frame)

- Two concentric circles are centered at a transmitting node. The smaller circle stands for the “transmission range” while the larger one stands for the “interference range.” Within the interference range, a station can sense the existence of other nodes’ signals. However, only when the receiving station is within the transmission range of the sending node, will the packets be guaranteed to reach the receiving station successfully.

- An IEEE 802.11 (b) data frame is depicted by an arrow with a “DATA” annotation.
- An IEEE 802.11 (b) acknowledgement packet is depicted by an arrow with an “ACK” annotation.

Summary

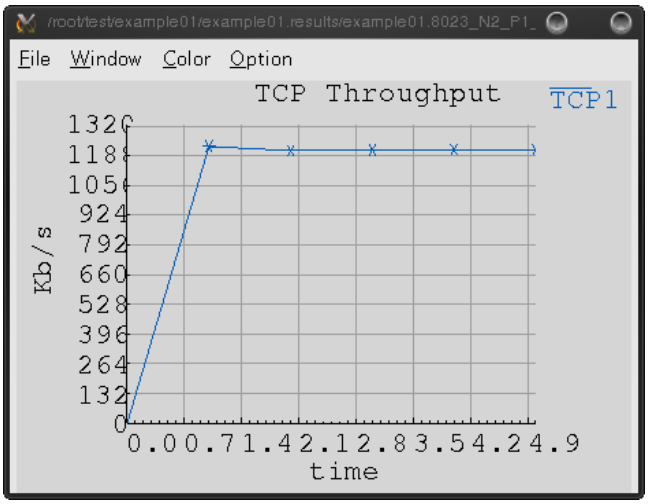
This chapter presents the “Packet Animation Player” capability of the GUI program. In this chapter, relevant options are covered. In addition, both wired and wireless packet animation effects are illustrated and explained.

6. Performance Monitor

Performance monitor is a generous-purpose and useful tool that can graphically display plots of performance metrics. For example, it can help users monitor a links' utilization or a TCP connection's achieved throughput. This chapter gives an overview of the functions provided by the performance monitor.

Running the Performance Monitor

A user can execute the **Menu -> G_Tools -> Plot Graph** command to launch the performance monitor. The following figure shows the window of the performance monitor.



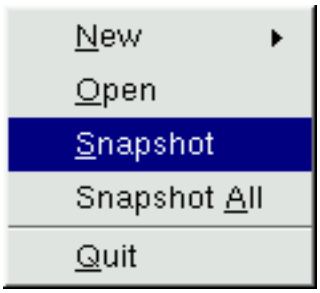
From the performance monitor (**PM**) window, a user can execute the **PM.Menu -> File -> Open** command to select a desired log file to open.

The user can then left-click the start icon (▶) of the time bar at the bottom of the screen. As the packet animation proceeds, the performance monitor window will display the corresponding performance curves over time. Note that the performance monitor can be used as an independent tool without the animation player running. That is, it can read a log file generated by any other application program as long as the log file uses the two-column (X, Y) format.

Operations on the Performance Monitor

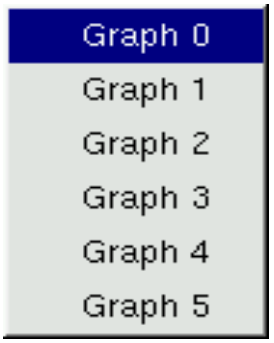
Several other commands are provided in the menu of the performance monitor window. In the following, we will explain their usages.

PM.Menu -> File



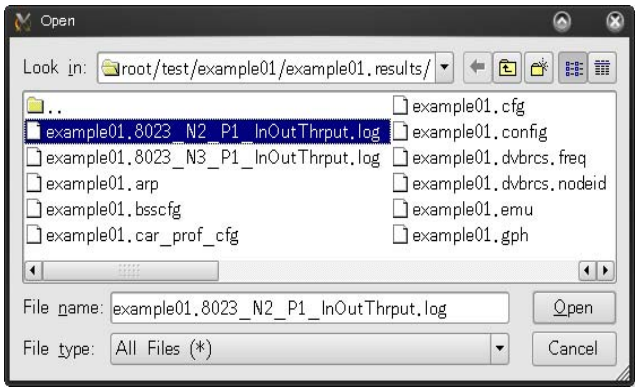
New

When a user executes this command, a new graph window will be opened. Up to six graph windows can be shown on the screen at the same time.



Open

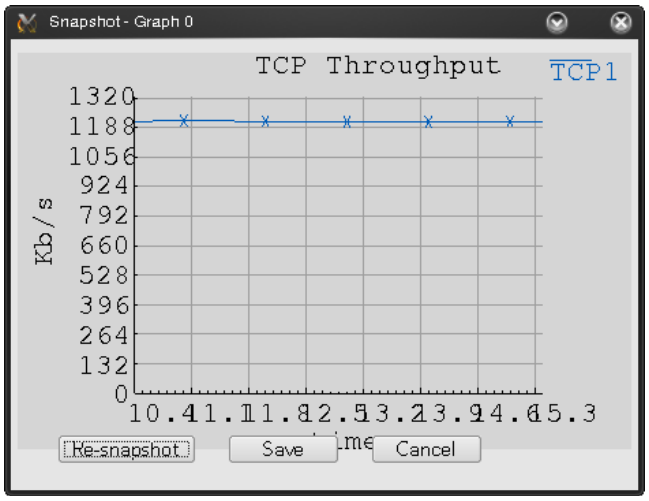
A user can execute this command to open a desired log file as a graph window's data source file. The specified log file will be associated with the graph window. Normally, log files are generated by the simulation engine if the user selected to do so in some protocol modules (e.g., 802.3 or 802.11 modules) in the node editor. However, they can also be generated by application programs running on nodes such as rtg.



The example01.8023_N2_P1_InOutThrput.log is a log file generated by the simulation engine and can be plotted by the

Snapshot

A user can execute this command to pop up the snapshot window for capturing the performance curve that is currently displayed in the window.



In this window, clicking “Re-snapshot” button will re-capture the performance curve that is being displayed. Clicking “Save” button will save the snapshot as an image file of the “bmp” type. Clicking “Cancel” will quit the window.

Snapshot All

A user can execute this command to take snapshots of all existing graph windows. The feature is very useful for comparing different performance metrics at the same time.

Quit

A user can execute this command to quit the current graph window.

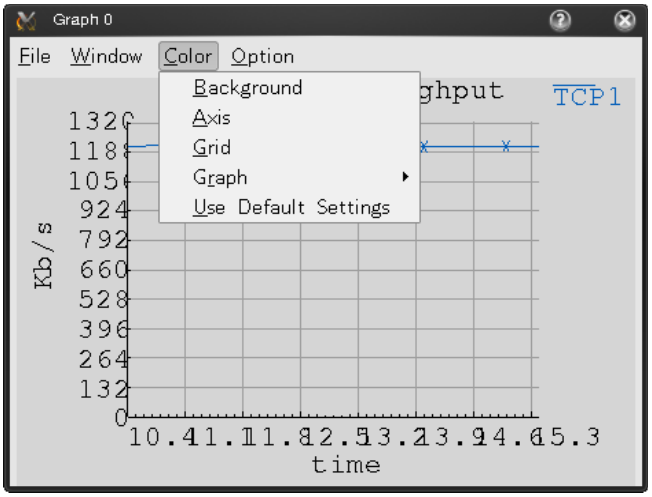
PM.Menu ->Window

Add/Remove Graph

This command provides a sub-menu from which a user can choose different graph data source files. Selected graph data source files are headed with check marks. A user can use this command to display the performance curves of more than one graph source files in the same window. It is useful for comparing different performance metrics at the same time.

PM.Menu ->Color

Several commands are provided under the color sub-menu for setting the colors of the different parts of the graph window.



Background

Executing this command can select a color from the palette and set it as the background color of the current graph window.

Axis

Executing this command can select a color from the palette and set it as the color of the X and Y axes of the current graph window.

Grid

Executing this command can select a color from the palette and set it as the color of grids of the current graph window.

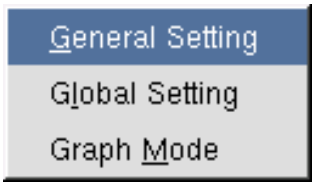
Graph

This command provides a sub-menu from which a user can choose a different graph data source file to display its performance curve. In addition, the user can select a color from the palette and set it as the color of the performance curve in the current graph window.

Use Default Settings

Executing this command will use the default colors for the background, axes, and grids of the current graph window.

PM.Menu ->Option



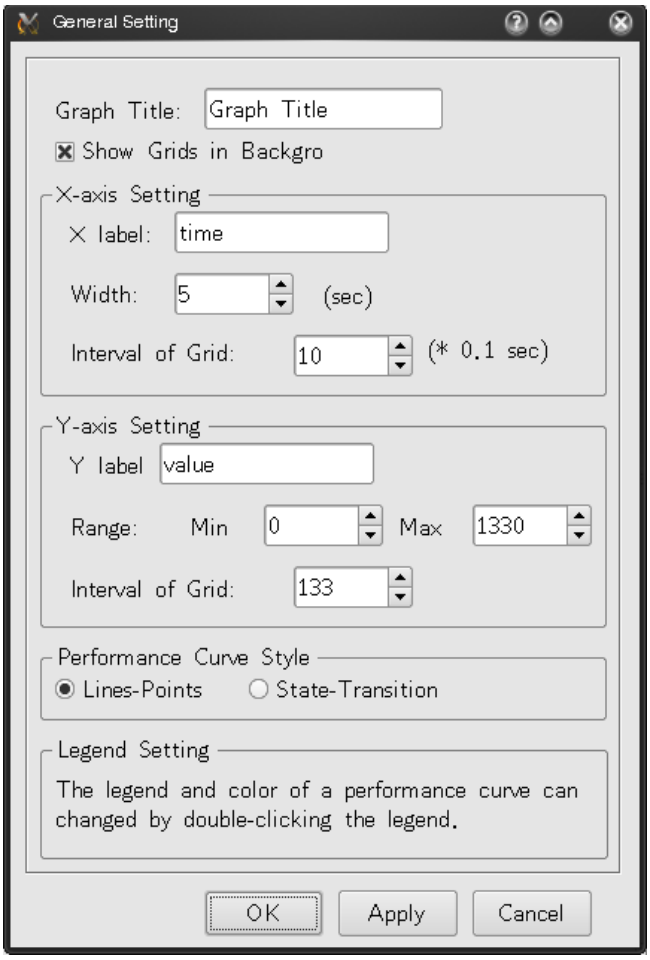
General Setting

Executing this command can set the various presentation parameters of a graph window. The following figure shows the dialog box of this command.

Graph Title:
This field sets the title of the graph.

Show Grids in Background:
This field sets whether the grids should be visible.

X label:
This field sets the label of the X axis.



Width (X-axis):
This field specifies how many seconds' worth of data should be displayed in the graph window.

Interval of Grid (X axis):
This field sets the grid interval of the X axis. This value will be multiplied by 0.1 to derive the interval between two consecutive grids on X axis.

Y label:
This field sets the label of the Y axis.

Range - Y Min:
This field sets the minimum value of the Y axis.

Range - Y Max:
This field sets the maximum value of the Y axis.

Interval of Grid (Y axis):
This field sets the grid interval of the Y axis.

Performance Curve Style - Line-Points:
Selecting this option specifies that the performance curve

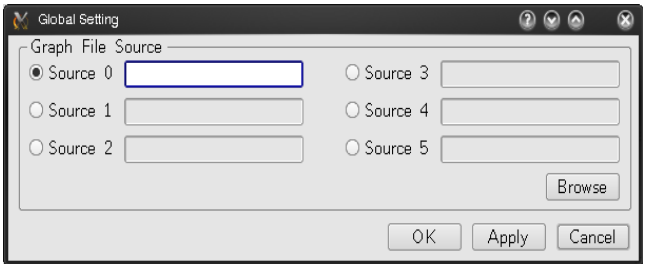
should be drawn using straight lines to connect adjacent points.

Performance Curve Style - State-Transition:
Selecting this option specifies that the performance curve should be drawn using horizontal lines to connect adjacent points.

In addition to the above settings, a performance curve's legend and color can be easily set by double-clicking the curve's legend located at the top-right corner. For example, a user can double-click the default "graph X" curve legend to change it.

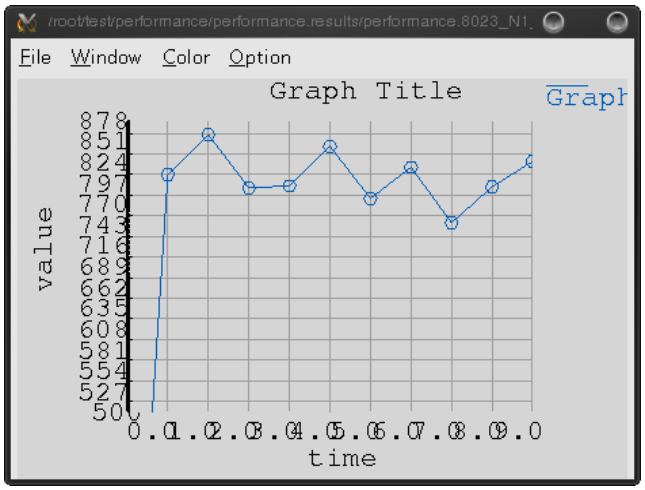
Global Setting

Executing this command can associate a graph data source file with a log file. Up to six associations can be specified in this dialog. To select a log file from the local host, a user can press the "Browse" button.

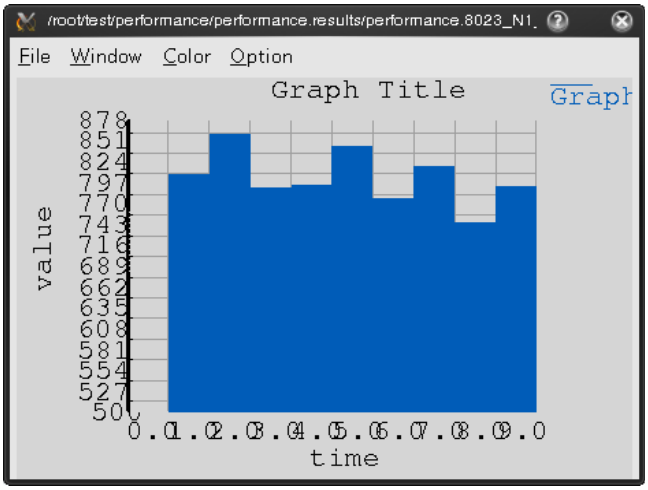


Graph Mode

Executing this command can control how to display a performance curve. Currently there are two modes. The first mode is "line points" while the second mode is "state transition." The following two screen shots clarify the differences between these two modes.



The performance curve is plotted using the line-point format.



The performance curve is plotted using the state-transition format.

Summary

This chapter presents the functions and relevant settings of the performance monitor. A user can use this tool to analyze performance results. In addition, a user can easily take important snapshots of some performance curves to make reports.

7. Emulation

The NCTUns network simulator can be easily turned into an emulator. An emulator allows real-world devices to interact with a simulated network and forces real-world packets to experience user-specified network conditions. Emulation is very useful for testing the functions and performances of real-world devices and observe how it would perform under various network conditions. In this chapter, we present how to turn NCTUns into an emulator.

Emulation in NCTUns

NCTUns supports emulations [1]. In an emulation, a real-world host, an ad-hoc mode mobile host, an infrastructure mode mobile host, or a router can exchange its TCP/UDP/ICMP packets with any node in a simulated network. These real-world devices are called external host, external ad-hoc mode mobile host, external infrastructure mode mobile host, and external router, respectively. In addition, NCTUns supports a new node type called “virtual router,” which is used for conducting distributed emulations and will be explained separately in another chapter. To represent them in an emulation network topology, these devices have their own node icons, which are shown here.  .

In addition to the above usage, two real-world hosts (including mobile hosts in the following discussion) can exchange their packets via a simulated network. For example, a TCP connection can be set up between two real-world hosts with their packets traversing a network simulated by NCTUns in real time.

Emulation provides several advantages. First, real-world traffic and simulated traffic can interact with each other. Second, real-world traffic can be subject to user-specified packet delay, drop, reordering, and packet scheduling and/or buffer management schemes. With emulation, we can test the function and performance of a real-world host (actually the host can be any device with an IP address) and see how it would perform under various network conditions without getting, knowing, or modifying its internal protocol stack.

Emulation is achieved by 1) specifying to which node in a simulated network an external host/router should be connected; 2) physically connecting the external host/router to the simulation machine via a network; 3) setting the speed of the simulation engine to be as fast as the real-world clock; and 4) add some settings on the simulation machine and external real-world hosts/routers, so that real-world traffic can be directed to and received from the simulated network.

To describe the connectivity between an external host/router and a simulated network (i.e., to specify to which node in the simulated network the external host/router is attached), each real-world external host/router is represented as an external host/router icon in the simulated network. A GUI user can easily specify to which node in the simulated network an external host/router should connect by drawing a link between these two nodes. Like all other links in the simulated network, such a link has its own properties and is simulated by NCTUns.

To let the packets generated by an external host enter the simulated network or let an external host receive packets originated from the simulated network, the external host must be physically connected to the simulation machine via some network (which can be as simple as an Ethernet cable). Ideally, such a network should have infinite bandwidth and zero latency. Although in the real world such a network does not exist, for achieving accurate results, the used network should still have low latency and high bandwidth. For example, a 100 Mbps Fast Ethernet network may be used for this purpose. **One should notice that, for NCTUns, an external host must reside on the same subnet as the simulation machine; otherwise, the emulation function will not work properly.**

NCTUns uses an emulation kernel module to seamlessly bridge the real-life network and the simulated network. This kernel module performs the **Network Address Translation** (**NAT**) function: It intercepts incoming/outgoing packets, properly modifies their IP addresses and port numbers, and finally injects them into either the simulated network or the external real-life network according to their destination IP addresses. The detailed design and implementation information is available in [1].

After specifying the emulation topology, the nctunsclient program will automatically generate the commands required for setting up the emulation kernel module. Then, when starting an emulation, the NCTUns simulation engine will trigger the Linux kernel to properly load and initialize the emulation kernel module using the specified commands via system calls. Because the emulation kernel module consumes some CPU time to perform the required NAT function, it is recommended to conduct an emulation using a high-speed machine.

In the following, we illustrate the detailed steps to configure an emulation case using the GUI program.

The Simulation Speed Setting for Emulation

Once a user adds an external host into the network topology, the speed of the simulation engine will automatically be set to the speed of the real-world clock. During the simulation, the simulation's simulation clock will then be synchronized with the real-world clock every 1 ms. Therefore, the emulation function's latency precision is 1 ms.

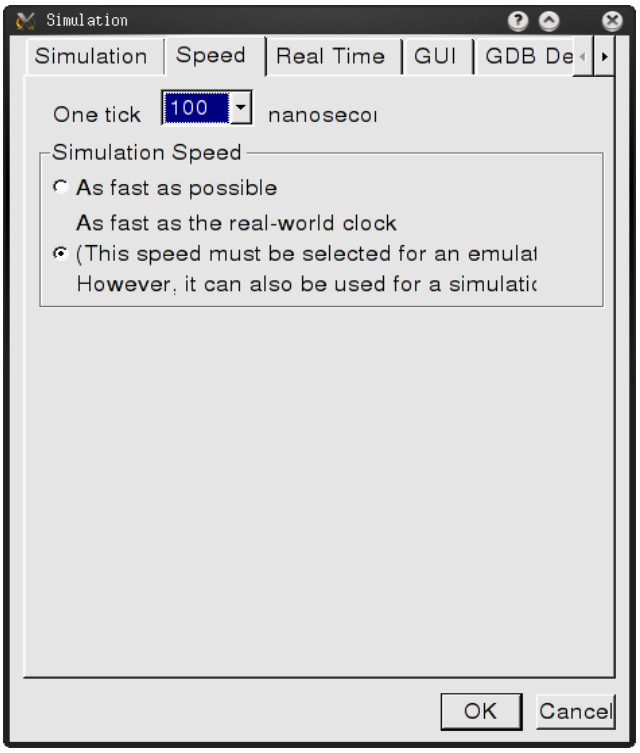
From experimental results, it is found that the precision may degrade and vary if NCTUns is used in its single-machine mode. During an emulation, the GUI program, simulation engine, traffic generator application programs, and some daemon programs all need to be run on the single machine. Because they need to compete for the machine's CPU cycles, the emulation precision may degrade. However, it has been found that if NCTUns is used in its multiple-machine mode, the precision is quite high and does not degrade.

When all external hosts are removed from the network topology, purposely the GUI is designed not to automatically switch the speed option back to "As fast as possible." This is because even though there is no external host in a network topology, sometimes it is still useful to let a simulation run at the speed of the real-world clock. For example, when a GUI user wants to use the command console function during a simulation, he (she) may want the simulation to run at the real-world clock speed. For the same reason, even if a case is a simulation rather than an emulation, the simulation speed option can still be set to "As fast as the real-world clock."

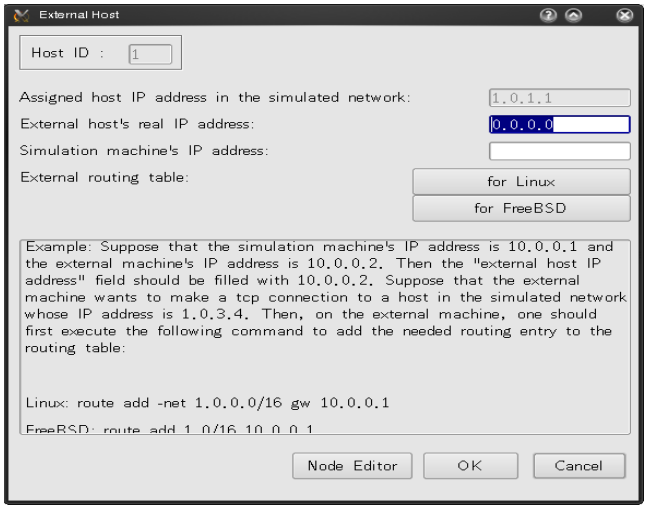
Insert External Host into a Network Topology

First, a user can click on the external host icon on the tool bar  and add it to the network topology. Second, he (she) then switches to the "Edit Property" mode and enters the IP address used by the external host in the real world. This information must be known by the emulation kernel module otherwise it cannot forward packets originated from the simulated network to the external host. In addition to the above information, the user needs to enter the IP address used by the simulation machine in the real world.

The assigned host IP address is the IP address assigned to this external host in the simulated network. If a node in the simulated network wants to actively send packets to the external host, the node can use the external host's assigned IP address as these packets' destination IP addresses. These packets will then traverse the simulated network and reach



the external host in the simulated network. With the IP address mapping specified here, the emulation kernel module will intercept these packets and then forward them to the external host in the real world.



Direct Traffic to the Simulated Network

Suppose that in the real world the simulation machine's IP address is 10.0.0.1 and the external machine's IP address is 10.0.0.2 and they are physically connected via a crossover Ethernet cable. Suppose that the external machine wants to

make a TCP connection to a node in the simulated network whose assigned IP address is 1.0.3.1. Then on the external machine, the user should first execute the following FreeBSD command to add the required routing entry to the system routing table.

route add 1.0/16 10.0.0.1

In the above command, 1.0/16 means that the destination network address is 1.0.X.X. (16 means that the netmask is 255.25.0). Note that every node in the simulated network is assigned an IP address of the form of 1.0.X.X. As a result, the above command indicates that all outgoing packets whose IP destination address is 1.0.X.X should be first sent to the gateway whose IP address is 10.0.0.1. In this case, since 10.0.0.1 is the simulation machine's IP address, these packets will be sent to and received by the simulation machine.

If the external machine is a Linux machine, the needed routing command should be as follows:

route add -net 1.0.0.0/16 gw 10.0.0.1

Emulation Examples

In the following, we illustrate how to use external host, external ad-hoc mode mobile host, external infrastructure mode mobile host, and external router in emulations.

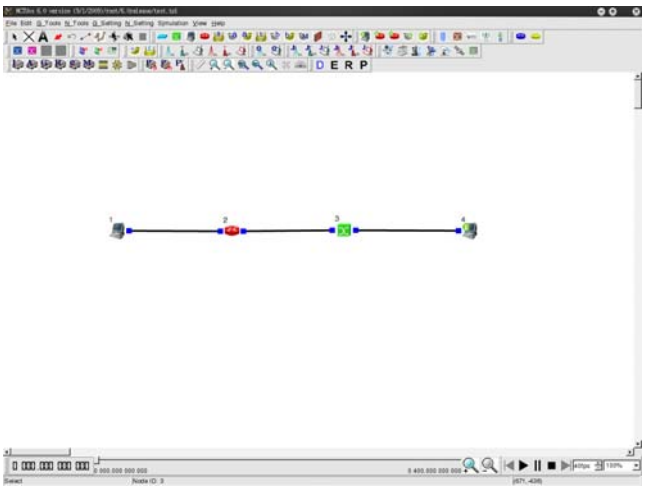
External Host

External hosts can be connected to a simulated network in several ways. In the following, we present three emulation examples.

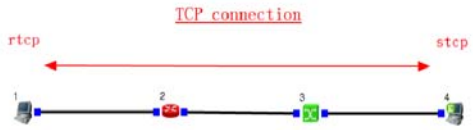
Example 1

The following figure shows the first example. In this figure, an external host is connected to the simulated network via a simulated link that sits between it and a simulated switch. The external host wants to exchange TCP packets with the host in the simulated network. Suppose that the IP address assigned to the simulated host is 1.0.1.1 and the IP address assigned to the external host in the simulated network is 1.0.2.1.

First, suppose that the external host wants to make a greedy TCP connection to the simulated host on the left. In such a case, the "rtcp -p 8000" command can be entered to the **[Application]** tab of the simulated host's dialog box. Doing so will run up a TCP receiving program on the simulated host during the emulation. After starting the emulation, the GUI user can execute the "stcp -p 8000 1.0.1.1" command on the

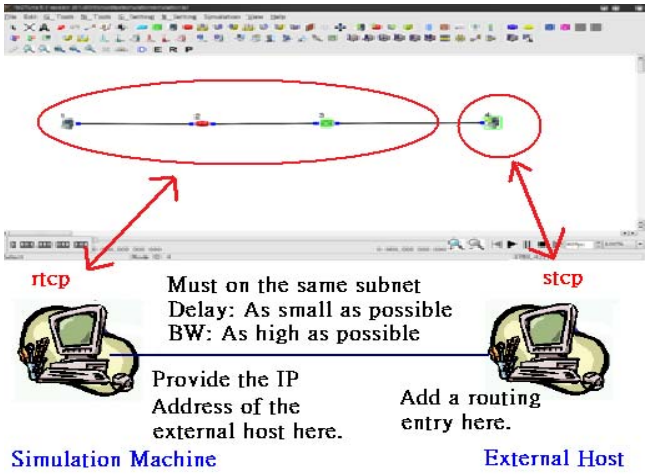


external host to run up the TCP sending program. The following figure shows this network and traffic configuration.



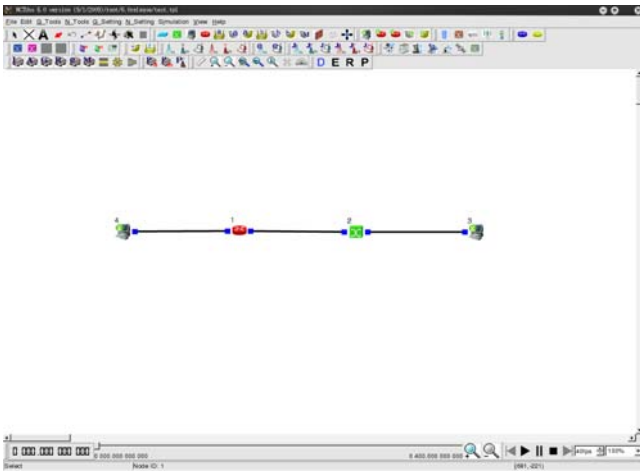
If the external host is physically connected to the simulation machine and its routing configuration has been properly set according to previous explanations, TCP packets will begin to be exchanged between the simulated host and the external host. The following figure shows the physical setup for this emulation case.

Second, suppose that the simulated host wants to make a greedy TCP connection to the external host. In such a case, the "rtcp -p 8000" command should be first run up on the external host waiting for the TCP connection setup request to come. Then the "stcp -p 8000 1.0.2.1" command can be entered to the **[Application]** tab of the simulated host's dialog box. Doing so will run up a TCP sending program on the simulated host during the emulation. When the emulation starts, TCP packets will begin to be exchanged between the simulated host and the external host.



Example 2

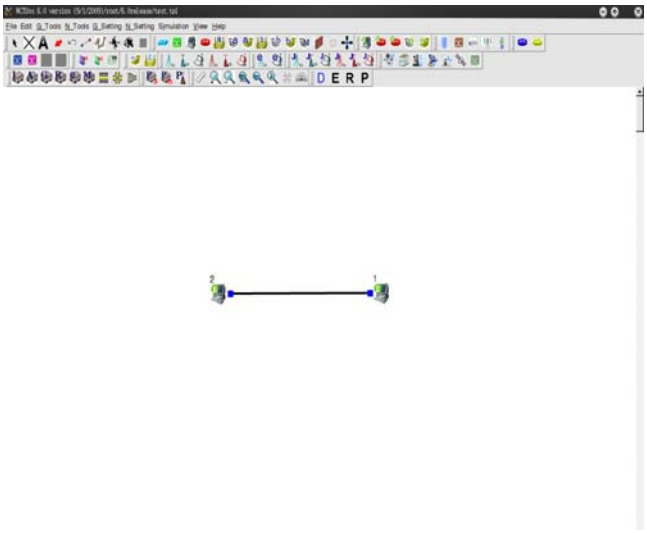
The following figure shows the second example. In this figure, two external hosts are connected to the simulated network. The right external host connects itself to the simulated switch while the left one connects itself to the simulated router. The two external hosts want to exchange their TCP packets via the simulated network. Suppose that the IP address assigned to the left external host is 1.0.1.1 and the IP address assigned to the right external host is 1.0.2.1.



Suppose that the left external host wants to make a greedy TCP connection to the right external host. In such a case, the "rtcp -p 8000" command should be first run up on the right external host. Then the GUI user can start running the emulation. The GUI user can then execute the "stcp -p 8000 1.0.2.1" command on the left external host to run up the TCP sending program. If the two external hosts are physically connected to the simulation machine and their routing configurations have been properly set, their TCP packets will begin to be exchanged via the simulated network. That is, their TCP packets will traverse the simulated link, switch, and router.

Example 3

The following figure shows the third example, which is intended to show that an emulation topology can be very simple. In this figure, two external hosts are connected to the simulated network and the simulated network is just a link. The left external host connects itself to the left end of the link while the right one connects itself to the right end of the link. The two external hosts want to exchange their TCP packets via the simulated link. Assume that the IP address assigned to the left external host is 1.0.1.1 and the IP address assigned to the right external host is 1.0.1.2.

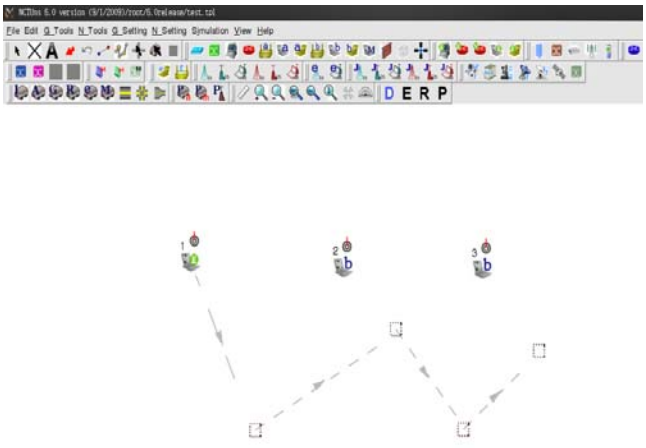


Suppose that the left external host wants to make a greedy TCP connection to the right external host. In such a case, the "rtcp -p 8000" command should be first run up on the right external host. Then the GUI user can start running the emulation. The GUI user can then execute the "stcp -p 8000 1.0.1.2" command on the left external host to run up the TCP sending program. If the two external hosts are physically connected to the simulation machine and their routing configurations have been properly set, their TCP packets will begin to be exchanged via the simulated network. To purposely delay, drop, reorder real-life packets while they are exchanged on the simulated link, a user can put a WAN node on the link to achieve these effects.

External Ad-hoc Mode Mobile Node

For emulation, an external ad-hoc mode mobile node in the real-world need not be a mobile device (e.g., a notebook computer equipped with an IEEE 802.11 interface). Actually, it can be a fixed host which uses a normal Ethernet link to connect to the simulated network. Because the external mobile node's IEEE 802.11 MAC protocol is simulated in the simulated network, the IEEE 802.11 MAC protocol on the real-life external mobile node is not used between the external mobile node and the simulation machine to exchange their packets. In addition, mobility is simulated by the simulator rather than by the user physically moving the external mobile device around the simulation machine. For these reasons, the external mobile device actually can be a fixed host.

The following figure shows an emulation example in which one external ad-hoc mode mobile host communicates with a simulated mobile host via another simulated mobile host. Initially, the external mobile host on the left can exchange packets with the simulated mobile host on the right via the middle mobile host. However, as time proceeds, the mobile host on the left begins to move away from the simulated mobile host (not in the real-world but in the simulated network) and eventually it will be away from the transmission range of the middle mobile host. At this time, it can no longer communicate with the simulated mobile host on the right via the middle mobile host.



The physical setup for this emulation case is one simulation machine and one external mobile host (need not be mobile). The external mobile host can use either a normal Ethernet link to connect to the simulation machine or an IEEE 802.11(b) wireless interface. Actually, it does not matter which type of network link is used between the simulation machine and the external mobile host as long as their IP packets can be exchanged on the used network media.

As in the external host emulation case, the simulation machine and the external mobile host should be on the same subnet. Let's assume that the simulation machine's IP address is 10.0.0.1 and the external machine's IP address is 10.0.0.2 and they are physically connected via a Fast Ethernet crossover cable. Then on the external mobile host, the user should first execute the following command to add the required routing entry to its system routing table.

route add 1.0/16 10.0.0.1 (on FreeBSD)

route add -net 1.0.0.0/16 gw 10.0.0.1 (on Linux)

Also, if a node (either a simulated node or an external mobile node) wants to send packets to another node (either a simulated node or an external mobile node), it should use the IP address assigned to that node in the simulated network.

In short, the usage of external ad-hoc mode mobile host is the same as that for external host.

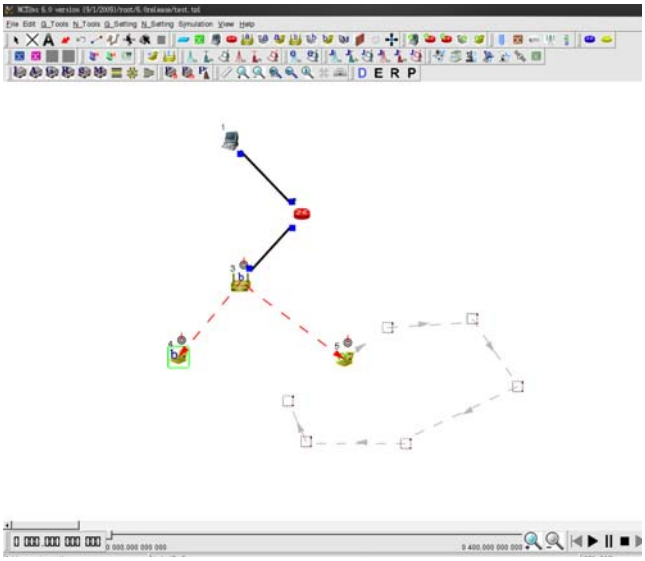
External Infrastructure Mode Mobile Host

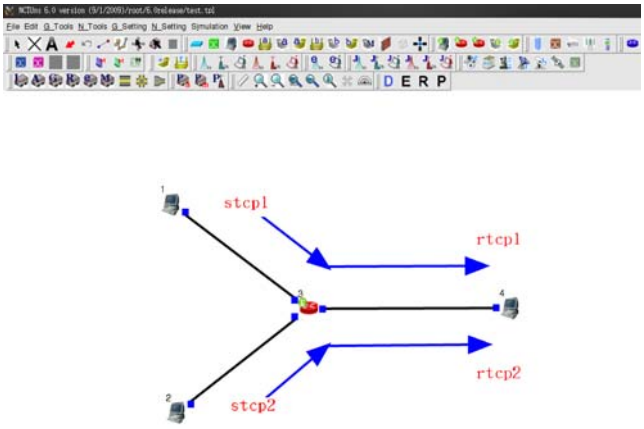
The usage of external infrastructure mode mobile host is every similar to those of external host and external ad-hoc mode mobile host. The only exception is that in the GUI dialog box of the external infrastructure mode mobile host, the user needs to provide the gateway IP address information. This requirement is reasonable as in the GUI dialog box of a normal infrastructure mode mobile node (in the **[Interface] tab**), the user also needs to provide such information.

The following figure shows an emulation example in which one external infrastructure mode mobile host communicates with a simulated host via a simulated wireless access point.

Like in the external ad-hoc mode mobile host case, initially the external infrastructure mode mobile host can communicate with the host at the top. However, as time goes by, it will eventually leave the coverage area of the wireless access point and no longer can communicate with that host.

The physical setup and routing configuration for this case is the same as that used for the external ad-hoc mode mobile host case.



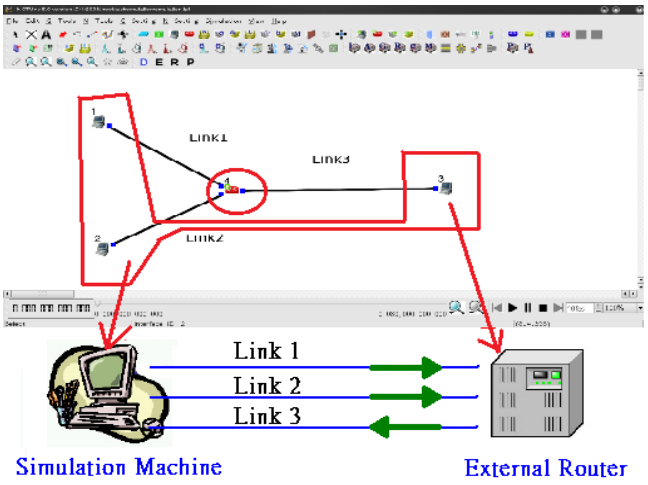


External Router

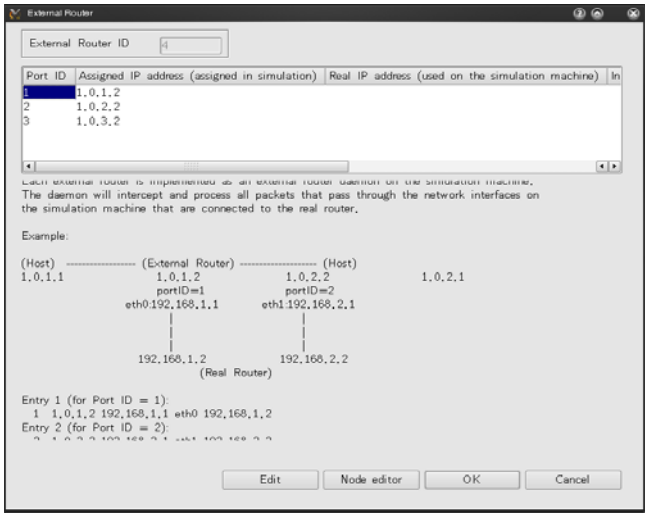
An external router can also interact with a simulated network. This is a very useful feature as traffic originated from the simulated network can be directed to the router, experience the router's packet scheduling and buffer management processing, and then return back to the simulated network. With this capability, we can easily test the router's functionality (e.g., sending virus and network-attack packets to see whether the router can detect them).

The following figure shows an emulation example case where three simulated hosts are connected to an external router. On top of this topology, we set up two greedy TCP connections. The first one starts at host 1 and ends at host 3 while the second one starts at host 2 and ends at host 3. The packets of these two TCP connections need to pass the external router. That is, they need to leave the simulated network (host 1 and host 1), enter the real-world network to reach the external router, leave the router, and then reenter into the simulated network (host 3).

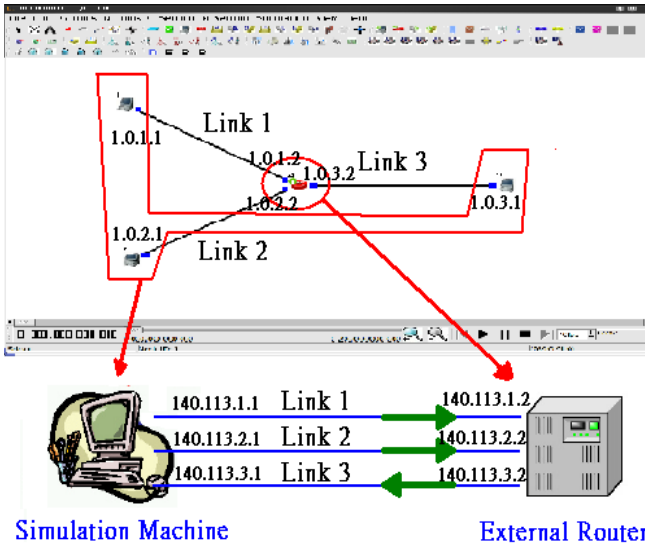
The physical network setup for running this emulation is shown as follows. The simulation machine needs to have three network interfaces each of which connects to one port of the external router. Clearly, three physical links are needed to connect these network interfaces to these ports -- one to one. These physical links are correspondingly represented as links in the simulated network, whose bandwidths and delays are specified in and simulated by the simulation machine. As in previous emulation cases, once real-world packets enter the simulated network, they need to traverse simulated links and subject to the bandwidth and delay of these simulated links.



The simulation engine needs some information about the external router. Thus, the user needs to provide some information in an external router's GUI dialog box, which is shown below. For each port of the external router in the real world, the user needs to provide the association among the following information entities: its assigned IP address in the simulated network (this information is automatically provided by the GUI in the second column of this association table after the port ID column), the real IP address of the network interface on the simulation machine that connects to this port via a link, the name (e.g., eth1) of the above interface (on the simulation machine), and the real IP address used by this port on the real-world router. The dialog box of the external router contains an example to illustrate the settings.



Using the emulation network settings depicted in the following figure as an example, assuming that the interface names for the 140.113.1.1, 140.113.2.1, and 140.113.3.1 on the simulation machine are eth1, eth2, and eth3, respectively, then the association table should contains the following entries: (1, 1.0.1.2, 140.113.1.1, eth1, 140.113.1.2) for port 1, (2, 1.0.2.2, 140.113.2.1, eth2, 140.113.2.2) for port 2, and (3, 1.0.3.2, 140.113.3.1, eth3, 140.113.3.2) for port 3.



On the external router in the real world, some routing entries need to be added to its routing table so that packets originated from the simulated network can be redirected back to the simulated network. The rules for generating these routing entries are as follows. For every host with 1.0.X.Y as its assigned IP address in the simulated network, we need to use the following commands to add the needed routing entries:

1) “route add 200.Z.X.Y -interface NICNAME” or “route add 200.Z.X.Y GatewayIPaddress.” (on FreeBSD)

2) “route add 200.Z.X.Y dev NICNAME” or “route add 200.Z.X.Y gw GatewayIPaddress.” (on Linux)

Here Z is a variable taken from the set of all subnet IDs used in the simulated network, NICNAME is the name of the interface on the external router (e.g., fxp0 or eth0), and GatewayIPaddress is the IP address of the interface on the simulation machine to which the external router would like to send packets with 200.Z.X.Y as their destination IP address.

Note that “200” must be used because the emulation kernel module changes the destination IP address of a packet (e.g., 1.0.X.Y) going to the real router to 200.0.X.Y so that the packet can be recognized by the router and be sent back by the external router to the simulated network correctly.

Beside changing the first number of the destination IP address from the default “1” to “200,” the emulation kernel module also changes the second number of the destination IP address from the default “0” to the ID of the subnet where the packet leaves the simulated network to enter the external router. This design is required. Without such a design, if there are two external routers in a simulated network, when a packet enters the simulated network after being sent to an external router and then coming back, the emulation kernel module will not be able to know from which subnet this packet should continue its journey over the simulated network. Suppose that host 2 on the left sends a packet to host 3 on the right. Then the destination IP address of the packet will be changed to 200.2.3.1 before being sent to the external router.

Using the above example to illustrate, suppose that link 1 is subnet 1, link 2 is subnet 2, and link 3 is subnet 3 in the simulated network. Further suppose that the IP address of host 1 is 1.0.1.1, the IP address of host 2 is 1.0.2.1, and the IP address of host 3 is 1.0.3.1, and the IP address of the external router on link 1 is 1.0.1.2, the IP address of the external router on link 2 is 1.0.2.2, and the IP address of the external router on link3 is 1.0.3.2. Suppose that in the real world the real IP address used by the external router port configured with 1.0.1.2 in the simulated network is 140.113.1.2, the real IP address used by the external router port configured with 1.0.2.2 in the simulated network is 140.113.2.2, and the real IP address used by the external router port configured with 1.0.3.2 in the simulated network is 140.113.3.2. Further suppose that on the simulation machine the IP address of the interface connecting to link1 is

140.113.1.1 in the real world, the interface connecting to link2 is 140.113.2.1, and the interface connecting to link3 is 140.113.3.1. These address settings are best viewed by the above figure.

For this example case, on the external router we need to execute the following routing commands to add the required entries.

(On FreeBSD)

route add 200.1.1.1 140.113.1.1

route add 200.2.1.1 140.113.1.1

route add 200.3.1.1 140.113.1.1

route add 200.1.2.1 140.113.2.1

route add 200.2.2.1 140.113.2.1

route add 200.3.2.1 140.113.2.1

route add 200.1.3.1 140.113.3.1

route add 200.2.3.1 140.113.3.1

route add 200.3.3.1 140.113.3.1

(On Linux)

route add 200.1.1.1 gw 140.113.1.1

route add 200.2.1.1 gw 140.113.1.1

route add 200.3.1.1 gw 140.113.1.1

route add 200.1.2.1 gw 140.113.2.1

route add 200.2.2.1 gw 140.113.2.1

route add 200.3.2.1 gw 140.113.2.1

route add 200.1.3.1 gw 140.113.3.1

route add 200.2.3.1 gw 140.113.3.1

route add 200.3.3.1 gw 140.113.3.1

These commands have the effect that all packets that originate from subnet 1, 2, or 3 and go to 1.0.1.1 will be sent to 140.113.1.1 via link1. Similarly, these commands have the effects that all packets that originate from subnet 1, 2, or 3 and go to 1.0.2.1 will be sent to 140.113.2.1 via link2 and all packets that originate from subnet 1, 2, or 3 and go to 1.0.3.1 will be sent to 140.113.3.1 via link3. If there are multiple hosts on a subnet in the simulated network, it is more efficient and convenient to use subnet routing rather than host routing to specify these routing entries. The following shows the routing commands for adding these subnet routing entries:

(On FreeBSD)

route add 200.1.1/24 140.113.1.1

route add 200.2.1/24 140.113.1.1

route add 200.3.1/24 140.113.1.1

route add 200.1.2/24 140.113.2.1

route add 200.2.2/24 140.113.2.1

route add 200.3.2/24 140.113.2.1

route add 200.1.3/24 140.113.3.1

route add 200.2.3/24 140.113.3.1

route add 200.3.3/24 140.113.3.1

(On Linux)

route add -net 200.1.1/24 gw 140.113.1.1

route add -net 200.2.1/24 gw 140.113.1.1

route add -net 200.3.1/24 gw 140.113.1.1

route add -net 200.1.2/24 gw 140.113.2.1

route add -net 200.2.2/24 gw 140.113.2.1

route add -net 200.3.2/24 gw 140.113.2.1

route add -net 200.1.3/24 gw 140.113.3.1

route add -net 200.2.3/24 gw 140.113.3.1

route add -net 200.3.3/24 gw 140.113.3.1

Summary

This chapter presents how NCTUns can be turned into an emulator. Important concepts about emulation and detailed setup procedures are presented. Several emulation examples are also presented to help readers understand how to run an emulation case.

Reference

[1] S.Y. Wang and Y.M. Huang, “NCTUns Tool for Innovative Network Emulations,” a chapter of the “Computer-Aided Design and Other Computing Research Developments” book, (ISBN 978-1-60456-860-8, published by Nova Science Publishers in 2009)

8. Distributed Emulation

Distributed emulation is a novel methodology that allows multiple machines to cooperatively conduct an emulation case. By using this methodology, the system resource (e.g., CPU cycles and main memory) required to run an emulation case can come from multiple machines, which greatly increases the scalability of emulations over NCTUns. In this chapter, we present in detail how to use NCTUns to conduct an emulation case on multiple machines using the distributed emulation methodology.

Advantages and Concepts

Network emulation is an approach that enables real-world devices to interact with a network simulated in real time. Most existing network emulators abstract a complex simulated network as a single router. They use a machine to simulate such a router in real time and connect it to real-world devices. The packets generated by the real-world devices are directed to the router. When these packets enter the router, the router gives them special treatments such as dropping, delaying, or reordering to simulate the bahavior of the original complex network. By this approach, one can evaluate the functions and performances of a real-world device under various simulated network conditions.

NCTUns seamlessly integrates simulation and emulation to provide unique advantages over most existing network emulators. In a NCTUns emulation, the network simulated in real time need not be abstracted as a single router with only a few simplified packet processing capabilities. Instead, the simulated network can be a large network composed of a large number of nodes and links. Actually, this simulated network, although used in an emulation, can be as complex as any network that can be simulated by NCTUns.

NCTUns uses a novel kernel-reentering simulation methodology so that simulated nodes can run real-world applications and use the real-world Linux TCP/IP protocol stack to exchange packets. Due to this property, in a NCTUns simulation, realistic traffic flows generated by real-world applications and TCP/IP protocol stack can be set up among nodes in the simulated network. When such a simulated network is purposely run in real time (for brevity, such a simulated network is called the “emulated network'” in this chapter), real-world devices can exchange their packets over the emulated network. These real-world packets can encounter the background traffic (e.g., HTTP/TCP traffic) generated inside the emulated network to experience more realistic network conditions caused by these traffic.

Beside allowing two real-world devices to exchange their packets over an emulated network, in a NCTUns emulation, the application running on a real-world device can set up real TCP/UDP connections with a real-world application running on a node in the emulated network. This unique capability can save the number of real-world devices that need to be used in an emulation. By changing the behavior of the application running on a node in the emulated network, one can observe whether a real-world device would respond correctly to the various (normal or abnormal) requests issued by that application.

When the number of real-world devices that need to connect to a NCTUns emulated network is large, the size of the emulated network is large, the number of applications that need to be run up on the emulated network is large, or the amount of real-world traffic exchanged over the emulated network is large, some problems may result. The first problem is that the NCTUns emulation machine may not have enough network interface cards (NIC) to independently connect to each of these devices. Ideally, the NCTUns emulation machine should use a NIC to connect to a real-world device so that these devices' traffic into or out of the NCTUns emulation machine will not be affected by one another. However, nowadays a PC normally can only accommodate four NICs at the most. Although this problem can be solved to a certian degree by using a multi-port switch and connecting one NIC of the emulation machine and all real-world devices to this switch, cares must be taken to ensure that the traffic generated by different real-world devices will not affect each other in the switch.

The second problem is that the emulation machine may not be fast enough to run the emulated network in real time. When a heavy aggregate packet traffic load is generated by these devices, the NCTUns emulation machine may fail to process these packets in real time. In such a case, the emulation fails to be an emulation.

The third problem is that, under a heavy load condition, even though the NCTUns emulation machine can barely run the emulated network in real time, the synchronization between its simulation clock and the real-world clock will become less accurate. This may cause the real-world packets exchanged over the emulated network to experience unnecessary extra delays or losses.

The fourth problem is that, when many applications need to be run up on the emulated network, the NCTUns emulation machine may not have enough main memory to run up all of these applications.

To overcome these problems, NCTUns provides a distributed emulation approach. By this approach, a large emulated network is divided into several smaller parts and each part is run by a NCTUns emulation machine. Each NCTUns emulation machine just needs to (1) emulate the nodes and links in its assigned part, (2) run the real-world applications that should be run up on these nodes, (3) exchange real-world packets between it and the real-world devices that are attached to some nodes in its assigned part, and (4) exchange packets with other NCTUns emulation machines when these packets need to traverse into other parts.

By properly dividing a large emulated network into several smaller parts such that each part can be emulated by a NCTUns emulation machine in real time, NCTUns can emulate a very large network with many real-world application programs launched on it and many real-world devices attached to it. The scale of such a distributed emulation can be very large and is only limited by the number of available machines that can participate in the distributed emulation.

The dsitributed emulation approach of NCTUns is a fully automatic approach that needs no manual modifications to configuration files for performing a distributed emulation. To perform a distributed emulation in NCTUns, one first decides how to partition the emulated network into several parts. Then one uses the GUI to construct the network topology of each part. Finally, one uses the "virtual router," which represents a real router or a crossover cable between two parts, to connect any two parts together where appropriate. After these operations, the GUI will intelligently and automatically generate appropriate network configuration files and send them to all emulation machines participating in the distributed emulation. When the distributed emulation is done, the GUI will collect simulation result files and packet log files from all participating emulation machines and intelligently merge these files together as if the emulation were totally performed on just one machine.

Using NCTUns, a user need not worry about how to modify the contents of the generated network configuration files to correctly perform a distributed emulation. Instead, the user can enjoy the many benefits of distributed emulation without such worries and headaches.

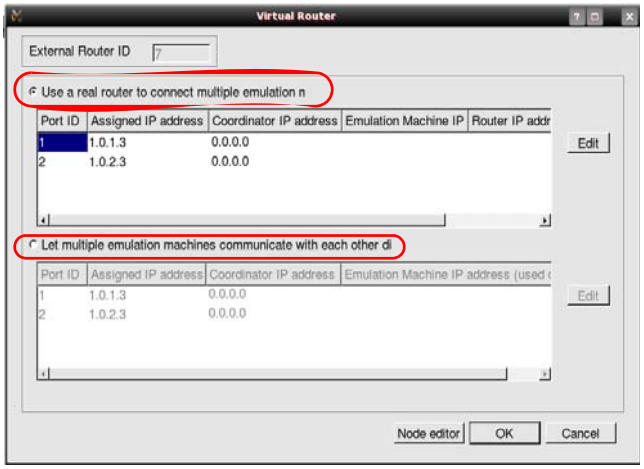
For simplicity, the three examples presented in this chapter do not include external hosts and external routers, which are presented in the previous chapter about "Emulation." Actually, they can participate in a distributed emulation as well.

Time Synchronization

As presented above, an emulation machine is responsible for processing the packet events generated by and destined to the nodes in the part assigned to it. When an event should be processed by another emulation machine, the local emulation machine should transmit the event to the remote emulation machine as fast as possible (ideally taking no time). During a distributed emulation, the simulation clock of each participating machine is independently synchronized with the real clock on its own machine every 1 ms. The real clocks on these machines may be different and they should be synchronized with each other by using the NTP protocol before a distributed emulation is conducted.

Virtual Router

NCTUns uses a "virtual router" node type () to divide the topology of an emulated network. A virtual router can represent a real router or simply a crossover cable (or a layer-2 switch, which can function as a crossover cable). The following figure shows the dialog box of a virtual router, which is composed of two panels that are exclusive to each other.



If the virtual router is used to represent a real router, one should tick the "Use a real router to connect multiple emulation machines" option to enable the top panel. On this panel, one can specify which machine is used to emulate a

part of the network. For each port of the virtual router, it has a corresponding entry in the table on the first panel. Each entry comprises five fields: 1) Port ID; 2) Assigned IP address (in the emulated network); 3) Coordinator IP address; 4) Emulation machine IP address; and 5) the IP address of the network interface on the real router that corresponds to this port. The meanings of these fields are explained below.

The **"Port ID"** field denotes the ID of the port under discussion. The **"Assigned IP address"** field shows the assigned IP address for this port in the emulated nework. The values of these two fields are automatically assigned by the GUI program.

The **"Coordinator IP address"** field specifies the IP address of the emulation machine whose coordinator program is responsible for forking a simulation engine process to emulate the part of network that this port connects with. If such an emulation machine has multiple IP addresses (i.e., it has multiple network interfaces participating in the distributed emulation. See Example 3 to be presented later), *the address chosen must be the address that its coordinator program uses to register with the dispatcher! It is the IP address of the network interface that is closest to the machine on which the dispatcher is running.*

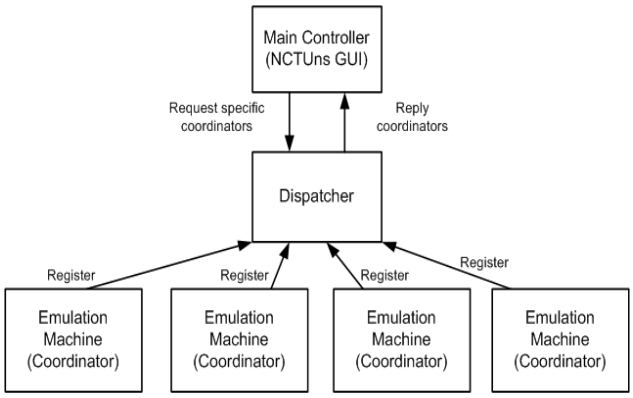
The **"Emulation Machine IP address"** field specifies the IP address of the above emulation machine. If the emulation machine has multiple IP addresses (i.e., it has multiple network interfaces participating in the distributed emulation, See Example 3 to be presented later), *the address chosen must be the address of the network interface that connects to this real router!* Normally, an emulation machine uses only one network interface to connect itself to a single virtual (real) router (see Example 1 and 2 to be presented later). In such a case, the **"Coordinator IP address"** and the **"Emulation Machine IP address"** specified in this virtual router will be the same. Finally, the **"IP address of the real router's interface"** field specifies the IP address of the interface of the real router that corresponds to this port.

If the virtual router is used to represent a crossover cable (or a layer-2 switch), one should tick the "Let multiple emulation machines communicate with each other directly" option to enable the bottom panel. On the this panel, each entry in the table is composed of four fields: Port ID, Assigned IP address, Coordinator IP address, and Emulation machine IP address. Their meanings are the same as their counterparts on the first panel. To save space, we do not explain them again here.

After a distributed emulation case is properly set up, one can click the "Run Simulation" button to enter the "Run Simulation" mode. At that time, the GUI program will generate emulation related files for the whole emulation case. The detailed setting on each real machine for emulating a part of the whole network is explained later. In the following, we first briefly explain the architecture of NCTUns for distributed emulations.

Distributed Emulation Architecture

NCTUns employs a central controller to manage all emulation machines for a distributed emulation case. The functions of the central controller are implemented in the GUI program and the dispatcher program. The GUI program is also called the main controller in terms of the distributed emulation architecture. The architecture of NCTUns for distributed emulations is shown in the following figure.



Setting Up a Distributed Emulation Case

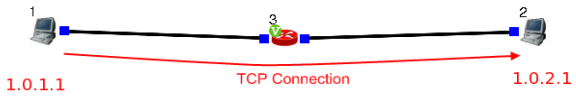
Before a distributed emulation case can be performed, the dispatcher program should be launched on a machine. After that, on each participating emulation machine, one should run up a coordinator. However, before running up a coordinator, one should modify the DISPATCHER_IP parameter in its coordinator.cfg file, which should be in the /usr/local/nctuns/etc/ directory. The default value for the DISPATCHER_IP parameter is 127.0.0.1, which means that the coordinator program should register itself with the dispatcher program running on the local machine. However, for a distributed emulation case, most of the coordinator programs launched should register themselves with the same dispatcher program running on a remote machine.

After starting all participating coordinator programs, one can start the GUI program. For the GUI program to correctly connect to the dispatcher, one should set the IP address of the dispatcher program in its Menu -> G_Setting -> Dispatcher panel.

So far, the setting for the central controller has been completed. In the following sections, we use several example cases to illustrate the remaining steps to configure distributed emulation cases with different network configurations.

Example 1

As shown in the following figure, a network is composed of two hosts and a virtual router. The virtual router splits the whole network topology into two parts. The host on the left part of the network intends to transmit TCP packets to the host on the right part of the network. The IP addresses assigned to these two hosts are 1.0.1.1 and 1.0.2.1, respectively.



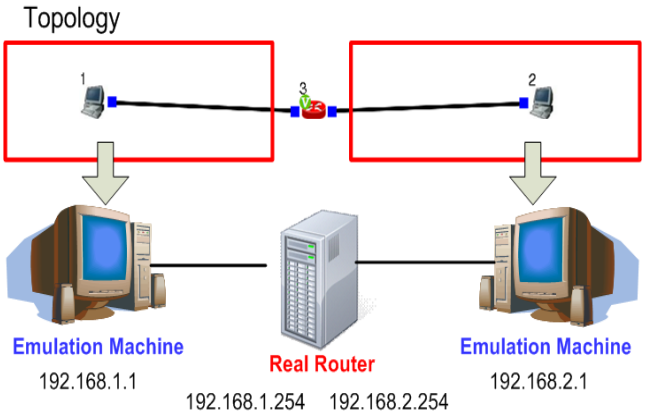
As explained previously, the virtual router can represent (1) a real router, or (2) a layer-2 switch or a crossover Ethernet cable. In the following, we first show the detailed steps for configuring a distributed emulation case where the virtual router represents a real router.

Use a real router to connect emulation machines

As shown in the following figure, a network is composed of two emulation machines and one real router. The IP addresses of these two emulation machines are 192.168.1.1 and 192.168.2.1, respectively, and these two emulation machines connect to the real router at the two interfaces with 192.168.1.254 and 192.168.2.254. If no other machine is used to run the central controller, one of these two emulation machines should be designated as the central controller. In this example, the dispatcher and the central controller (GUI) are run on the emulation machine assigned the IP address 192.168.1.1.

The first step that one should take is to physically connect these machines to form a connected network as shown in the above figure. One then runs the following route commands on the real router:

route add -net 200.2.1.0/24 gw 192.168.1.1



route add -net 200.1.2.0/24 gw 192.168.2.1

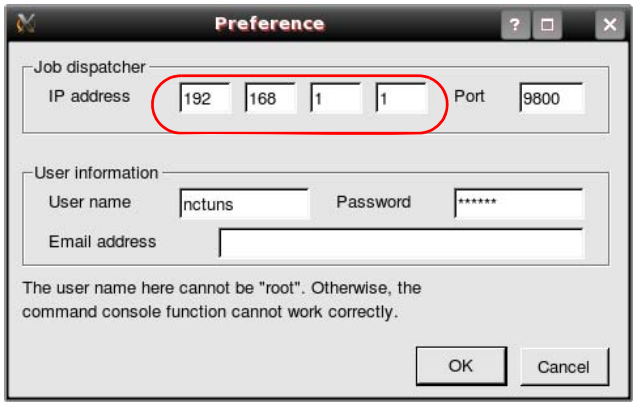
The rationale for executing these commands on a real router is explained here. A packet with a destination IP address, 200.Z.X.Y, indicates that this packet is from a subnet of 1.0.Z.0/24 (To be precise, Z does not denote the ID of the original source subnet of the packet but rather the ID of the last subnet on which the packet traverses before it is sent to this real router) and destined to a subnet of 1.0.X.Y. For example, the first route command will make the real router forward packets generated by the 1.0.2.0/24 subnet and destined to the 1.0.1.0/24 subnet to the real machine with the IP address 192.168.1.1, which is designated to emulate the subnet of 1.0.1.0/24.

The next step is to run up the dispatcher program on the emulation machine with the IP address 192.168.1.1.

The third step is to properly modify the coordinator.cfg file for all involved coordinator programs. Recall that the dispatcher program is run on the emulation machine with the IP address 192.168.1.1. Thus, one should modify the DISPATCHER_IP parameter in the coordinator.cfg file from 127.0.0.1 to 192.168.1.1 for each involved coordinator program (on each emulation machine), so that each coordinator will correctly know where the dispatcher program is and register itself with the same dispatcher program. After properly modifying the coordinator.cfg files for all involved coordinator programs, one can run up these coordinator programs on their respective emulation machines.

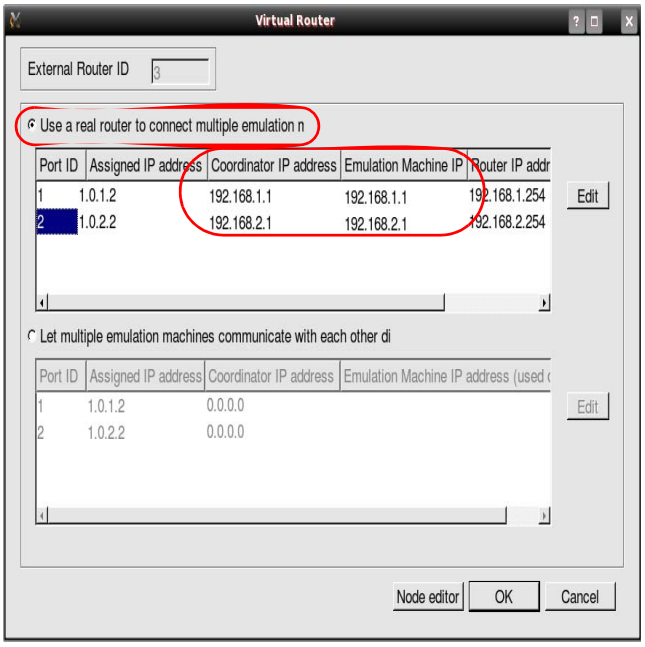
The fourth step is to run up the GUI program on the emulation machine with the IP address 192.168.1.1 and specify the Dispatcher IP address to be 192.168.1.1 in the panel **"Menu -> G_setting -> Dispatcher."**

Now, one can draw the network topology on the working area of the GUI. After finishing drawing the topology, one can switch the GUI to the Edit Property mode (the E mode).



In the E mode, one can set up the application programs that will be run during simulation. For example, we specify that the **"stcp -p 8000 1.0.2.1"** command should be run on the host with 1.0.1.1 and the **"rtcp -p 8000"** command should be run on the host with 1.0.2.1.

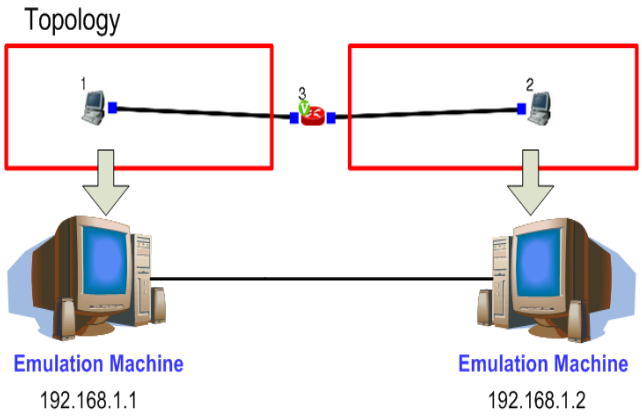
One then double-clicks the icon of the virtual router to pop up its dialog box. In this dialog box, one should enable the first option **"Use a real router to connect multiple emulation machines."** The detailed setting for this dialog are shown below.



After setting up the virtual router, one can switch the GUI to the "Run Simulation" mode and start running the distributed emulation case. The GUI will divide the emulated network into two parts and send the configuration files for each part to the emulation machine responsible for it.

Use a direct link to connect two emulation machines

If the virtual router does not represent a real router, it can represents a crossover link or a switch. As shown in the following figure, the two emulation machines are directly connected via a crossover Ethernet cable. Using this physical-network configuration, the virtual router is not mapped to any real device in the real world.



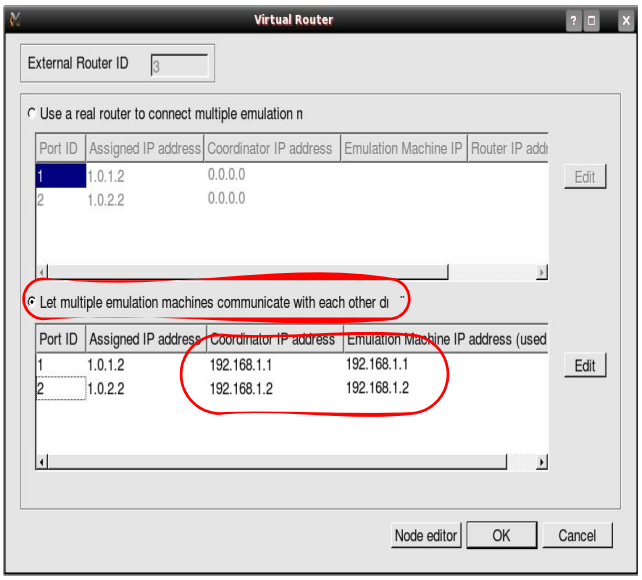
In this example case, the dispatcher program and the GUI program are run on the emulation machine with the IP address 192.168.1.1. That is, the "dispatcher" command is executed on the emulation machine with the IP address 192.168.1.1.

One then modifies the coordinator.cfg files for all involved coordinator programs. Because the dispatcher program is run on the emulation machine with the IP address 192.168.1.1, one should set the DISPATCHER_IP parameter in each coordinator.cfg file from 127.0.0.1 to 192.168.1.1, so that each coordinator program can correctly register itself with the same dispatcher program. After this is done, one can run up all involved coordinator programs on the two emulation machines.

The fourth step is to run up the GUI program on the emulation machine with the IP address 192.168.1.1 and set the Dispatcher IP address to 192.168.1.1 in the panel **"Menu -> G_setting -> Dispatcher."**

Now, one can draw the network topology on the working area of the GUI. After finishing drawing the topology, one can switch the GUI to the Edit Property mode (the E mode). In the E mode, one can set up the application programs that will be run during simulation. For example, we specify the "stcp -p 8000 1.0.2.1" command on the host 1.0.1.1 and the "rtcp -p 8000" command on the host 1.0.2.1 to run the stcp and rtcp programs on these two hosts during emulation.

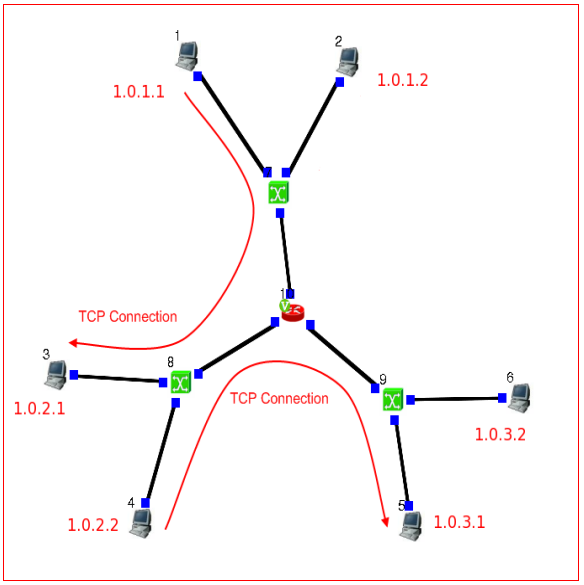
One then double-clicks the icon of the virtual router to pop up its dialog box. In this dialog box, one should tick the “Let multiple emulation machines communicate with each other directly” option to enable the bottom panel. The detailed setting for this dialog are shown below.



After setting up the virtual router, one can switch the GUI to the “Run Simulation” mode and start the distributed emulation case.

Example 2

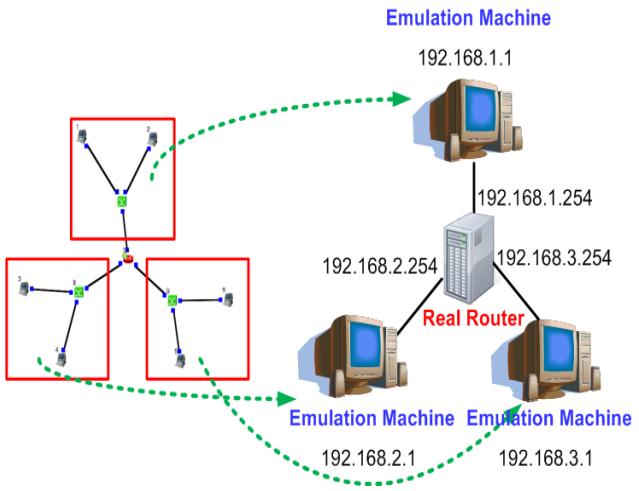
In example 2, we use one virtual router to partition the network topology shown in the following figure into three parts. The host “1.0.1.1” wants to establish a TCP connection with the host “1.0.2.1,” and the host “1.0.2.2” wants to establish a TCP connection with the host “1.0.3.1.”



Similar to example 1, this example case also has two possible physical network configurations. One is using a real router to connect the three emulation machines and the other is using a switch to connect the three emulation machines. The steps to configure these two cases are explained in detail below.

Use a real router to connect emulation machines

As shown in the following figure, the example network is composed of three emulation machines and one real router. The IP addresses of these three emulation machines are 192.168.1.1, 192.168.2.1, and 192.168.3.1, respectively. These emulation machines connect to the real router at its three interfaces. The IP addresses of these interfaces are 192.168.1.254, 192.168.2.254, and 192.168.3.254, respectively. In this example, the dispatcher program and the GUI program are run on the emulation machine with the IP address 192.168.1.1.



After configuring the physical network links, one should execute the following route commands on the real router.

route add -net 200.1.2.0/24 gw 192.168.2.1

route add -net 200.1.3.0/24 gw 192.168.3.1

route add -net 200.2.1.0/24 gw 192.168.1.1

route add -net 200.2.3.0/24 gw 192.168.3.1

route add -net 200.3.1.0/24 gw 192.168.1.1

route add -net 200.3.2.0/24 gw 192.168.2.1

The rationale for executing these commands on the real router is explained here. A packet with a destination IP address, 200.Z.X.Y, indicates that this packet is from a subnet of 1.0.Z.0/24 (To be precise, Z does not denote the ID

of the original source subnet of the packet but rather the ID of the last subnet on which the packet traverses before it is sent to this real router) and destined to a subnet of 1.0.X.Y. For example, the first route command will make the real router forward packets generated from the 1.0.1.0/24 subnet and destined to the 1.0.2.0/24 subnet to the real machine with the IP address 192.168.2.1, which is designated to emulate the subnet of 1.0.2.0/24.

The next step is to run up the dispatcher program. In this example, we run up it on the emulation machine with the IP address 192.168.1.1.

One then modifies the coordinator.cfg file on each emulation machine for the coordinator program running on this emulation machine. Because the dispatcher program is run on the emulation machine with the IP address 192.168.1.1, one should change the DISPATCHER_IP parameter in each coordinator.cfg file from 127.0.0.1 to 192.168.1.1 so that each involved coordinator program can correctly register itself with the same dispatcher program. After this is done, one can run up all involved coordinator programs on their respective emulation machines.

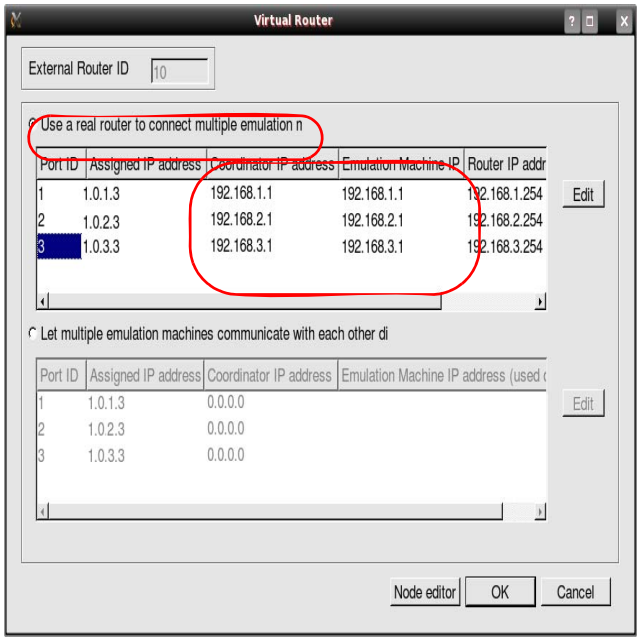
After starting all of these coordinator programs, one can run up the GUI program on the emulation machine with the IP address 192.168.1.1 and set up the Dispatcher IP address in **“Menu -> G_setting -> Dispatcher”**. One then draws the topology of the emulated network using the GUI and sets up the application programs to be run during the emulation. In this example, the commands to run the TCP application programs are listed below.

The command **“stcp -p 8000 1.0.2.1”** is run on the host “1.0.1.1” and the command **“rtcp -p 8000”** is run on the host “1.0.2.1.” The command **“stcp -p 9000 1.0.3.1”** is run on the host “1.0.2.2” and the command **“rtcp -p 9000”** is run on the host “1.0.3.1.”

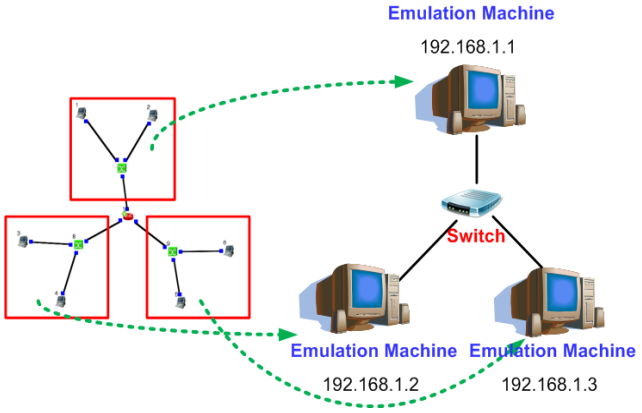
After setting up the traffic, one should double-click the icon of the virtual router to pop up its dialog box. In this dialog box, one should enable the first option “Use a real router to connect multiple emulation machines.” The detailed setting on the panel is shown as follows. After setting up the whole emulation case, one can switch the GUI to the Run Simulation mode and start the simulation.

Use a direct link to connect two emulation machines

An alternative to connect the three emulation machines is to connect them using a layer-2 switch. In such a physical network configuration, the virtual router does not correspond to any real device in the real world. As shown in the



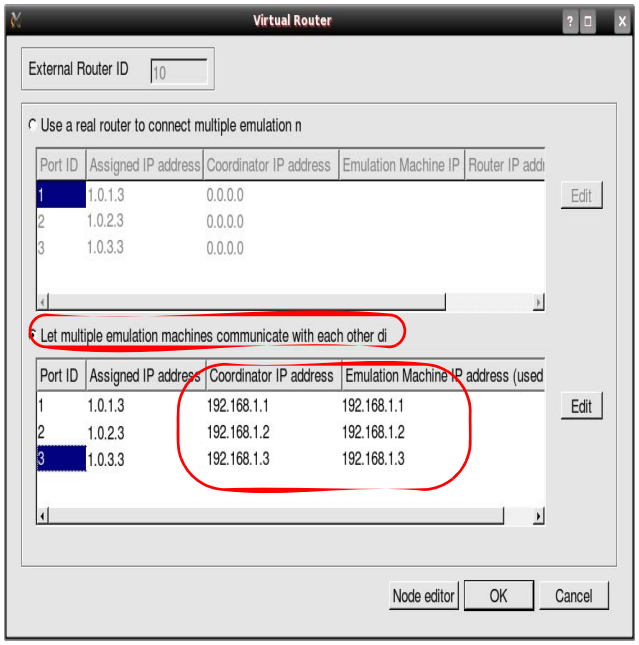
following figure, the dispatcher program and the GUI program are run on the emulation machine with the IP address 192.168.1.1.



The next step is to change the DISPATCHER_IP parameter of each coordinator.cfg file from 127.0.0.1 to 192.168.1.1 for each involved coordinator program. This is to make sure that each involved coordinator will register itself with the same dispatcher program. One then starts all coordinator programs on their respective emulation machines.

After this is done, one can run up the GUI program on the emulation machine with the IP address 192.168.1.1 and properly specify the Dispatcher IP address in the Menu -> G_setting -> Dispatcher panel. After drawing the topology of the emulated network and specifying the traffic setting, one double-clicks the icon of the virtual router to pop up its dialog box. Because the virtual router now does not represent

a real-life router, one should enable the “Let multiple emulation machines communicate with each other directly” option. The detailed setting of this dialog box for this example is shown below.



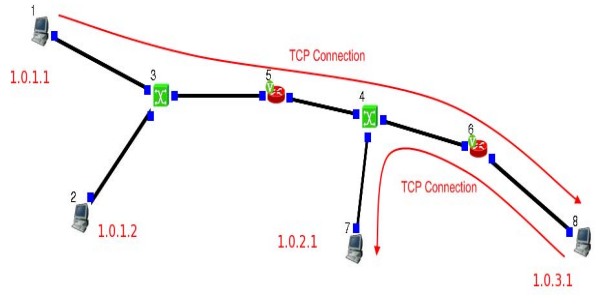
After finishing configuring the virtual router, one can switch the GUI into the “Run Simulation” mode and start running the distributed emulation.

Example 3

In example 3, we demonstrate a distributed emulation case that uses two virtual routers to partition the network topology into three parts. Note that it is important to properly configure the physical links among all emulation machines before the emulation is started. As shown in the following figure, the example topology contains two virtual routers. Each virtual router connects with two subnets and the 1.0.2.0/24 subnet is connected to both virtual routers. In this example case, the host 1.0.1.1 wants to establish a TCP connection with the host 1.0.3.1 and the host 1.0.3.1 wants to establish a TCP connection with the host 1.0.2.1.

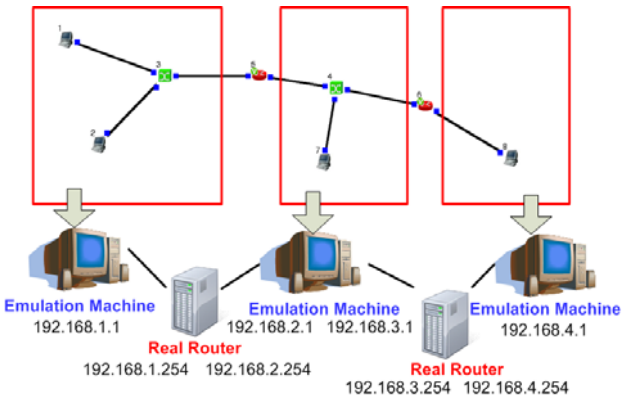
In this example case, we demonstrate the steps to configure the simulation case using two typical physical network configurations. In the first configuration, the two virtual routers are mapped to two real routers; in the second configuration the three emulation machines are connected via two switches.

Use two real routers to connect emulation machines



As shown below, the IP address of the emulation machine for emulating the left part of the network is 192.168.1.1 and that for the right part of the network is 192.168.4.1. The emulation machine for emulating the middle part of the network has two interfaces with IP addresses 192.168.2.1 and 192.168.3.1, respectively. Note that because the network interface with 192.168.2.1 is closer to the left emulation machine (where the dispatcher is run) than the other network interface, the coordinator running on this emulation machine uses 192.168.2.1 to register with the dispatcher. It is this reason why later when we configure the entries of the ports of the left and right virtual routers that connect to this emulation machine, the IP address specified in their **“Coordinator IP address”** fields should be the same and be 192.168.2.1.

The IP addresses used on the real router that connects the emulation machines 192.168.1.1 and 192.168.2.1 are 192.168.1.254 and 192.168.2.254; the IP addresses used on the real router that connects the emulation machines 192.168.3.1 and 192.168.4.1 are 192.168.3.254 and 192.168.4.254. In this example, the dispatcher program and the GUI program are run on the emulation machine with the IP address 192.168.1.1.



After setting up the physical links, two types of route commands should be properly set. The first one is for setting up the communication between the GUI central controller and each coordinator program in the real world. The second one is for setting up the communication between hosts in different parts of the emulated network.

The first type of the route commands required for this example case is shown as follows:

Router with IP address 192.168.1.254 and 192.168.2.254:

route add -net 192.168.3.0/24 gw 192.168.2.1

route add -net 192.168.4.0/24 gw 192.168.2.1

Router with IP address 192.168.3.254 and 192.168.4.254:

route add -net 192.168.1.0/24 gw 192.168.3.1

route add -net 192.168.2.0/24 gw 192.168.3.1

Emulation machines with IP 192.168.2.1 and 192.168.3.1

route add -net 192.168.1.0/24 gw 192.168.2.254

route add -net 192.168.4.0/24 gw 192.168.3.254

The second type of the route commands required for this example case is shown as follows:

Router with IP address 192.168.1.254 and 192.168.2.254:

route add -net 200.1.2.0/24 gw 192.168.2.1

route add -net 200.1.3.0/24 gw 192.168.2.1

route add -net 200.2.1.0/24 gw 192.168.1.1

Router with IP address 192.168.3.254 and 192.168.4.254:

route add -net 200.2.3.0/24 gw 192.168.4.1

route add -net 200.3.1.0/24 gw 192.168.3.1

route add -net 200.3.2.0/24 gw 192.168.3.1

The rationale for executing these commands on a real router is explained here. A packet with a destination IP address, 200.Z.X.Y, indicates that this packet is from a subnet of 1.0.Z.0/24 (To be precise, Z does not denote the ID of the original source subnet of the packet but rather the ID of the last subnet on which the packet traverses before it is sent to this real router) and destined to a subnet of 1.0.X.Y. For example, the first route command will make the real router forward packets generated from the 1.0.1.0/24 subnet and destined to the 1.0.2.0/24 subnet to the real machine with the IP address 192.168.2.1, which is designated to emulate the subnet of 1.0.2.0/24.

The setting of routes for this example is more complex than that used in the previous two examples. In this example case, the emulation machine in the middle needs to forward packets for other emulation machines. However, in the previous two example cases, this is unnecessary. For example, a packet from the host 1.0.1.1 to the host 1.0.3.1 needs to go through the subnet 1.0.2.0/24 to arrive its destination node “1.0.3.1.” This packet not only needs to be forwarded by the two real routers, but also needs to be forwarded by the emulation machine in the middle.

One then runs up the dispatcher program on the emulation machine “192.168.1.1” and properly modifies the coordinator.cfg file for each involved coordinator program. Because the dispatcher program is run on the emulation machine with the IP address 192.168.1.1, one should modify the DISPATCHER_IP from 127.0.0.1 to 192.168.1.1 for each involved coordinator program, so that each coordinator program can register itself with the same dispatcher program.

After this is done, one can run up all coordinator programs on their respective emulation machines and the GUI program on the emulation machine with the IP address 192.168.1.1. Recall that the Dispatcher IP address should be correctly specified in the panel **“Menu -> G_setting -> Dispatcher.”**

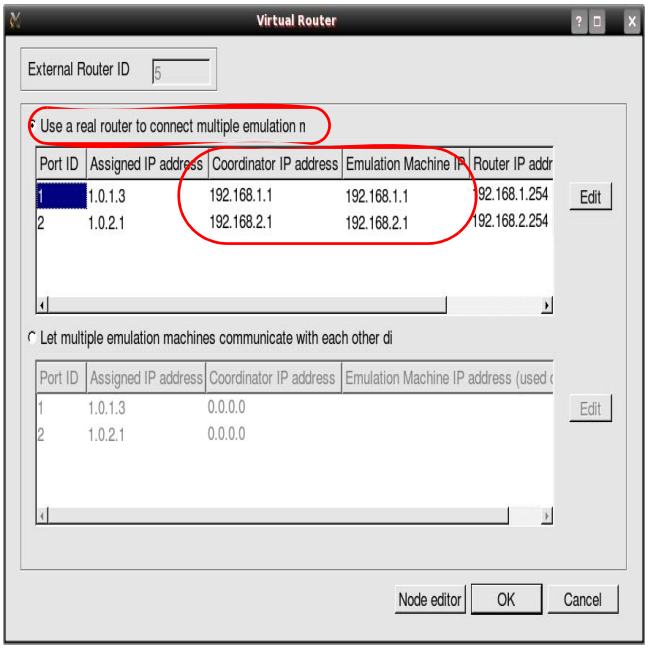
After setting up the network topology and the traffic, one then double-clicks the icon of the virtual router to pop up its dialog box. In this example, one should enable the first option “Use a real router to connect multiple emulation machines” because the virtual router represents a real router. The detailed settings for this panel on the two virtual routers are shown below. The first figure shows the dialog box of the virtual router connecting the 1.0.1.0/24 and 1.0.2.0/24 subnets and the second figure shows the dialog box of the virtual router connecting the 1.0.2.0/24 and 1.0.3.0/24 subnets.

Notice port 2 in the dialog box of the left virtual router and port 1 in the dialog box of the right virtual router. They both connect to the middle part. Because the coordinator running on the middle emulation machine uses 192.168.2.1 to register itself with the dispatcher (which is the interface that is closest to the left emulation machine where the dispatcher is running), both of their **“Coordinator IP address”** should be set to 192.168.2.1.

Regarding **“Emulation Machine IP address,”** the settings for these two ports are derived based on the definition explained at the beginning of this chapter. For port 2 of the left virtual router, it is the IP address of the network interface

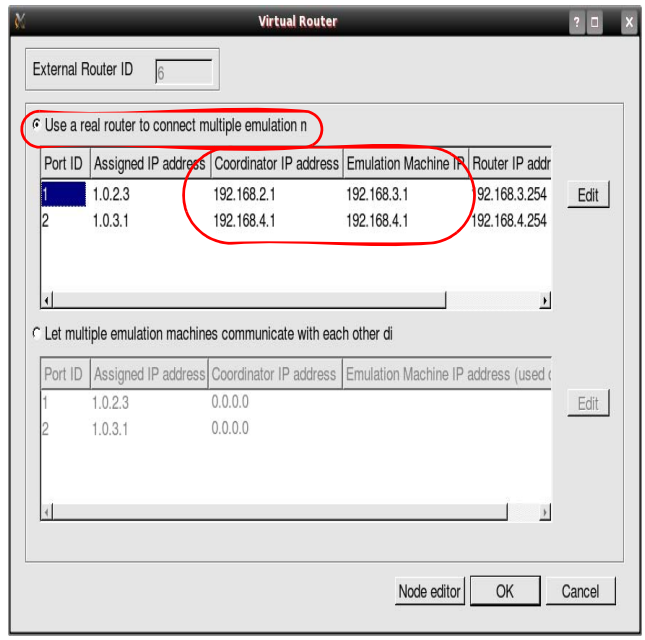
on the middle emulation machine that connects to this left virtual (real) router --- which is 192.168.2.1. For port 1of the right virtual router, it is the IP address of the network interface on the middle emulation machine that connects to this right virtual (real) router --- which is 192.168.3.1.

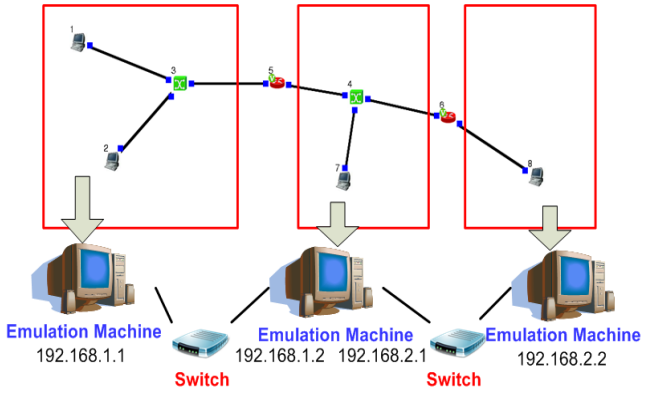
The above configurations must be set correctly as presented. Otherwise, the distributed emulation will not work correctly. After finishing these configurations, one can switch the GUI program to the “Run Simulation” mode and start to perform the distributed emulation.



Use a direct link to connect two emulation machines

If two emulation machines are connected via a layer-2 switch, they need to be on the same subnet. As shown in the following figure, the IP addresses of the emulation machines that emulate the left part and the righ part of the network are 192.168.1.1 and 192.168.2.2, respectively. The emulation machine that emulates the middle part of the network has two interfaces with the IP addresses 192.168.1.2 and 192.168.2.1, respectively. In this physical network configuration, one switch connects the subnets 192.168.1.1 and 192.168.1.2, and the other connects the subnets 192.168.2.1 and 192.168.2.2. **Note that one MUST NOT use only one switch to connect all emulation machines together for such a network.** Otherwise, the emulation machine that emulates the middle part of the network will not work correctly.





In this example, the dispatcher program and the GUI program are run on the emulation machine with the IP address 192.168.1.1.

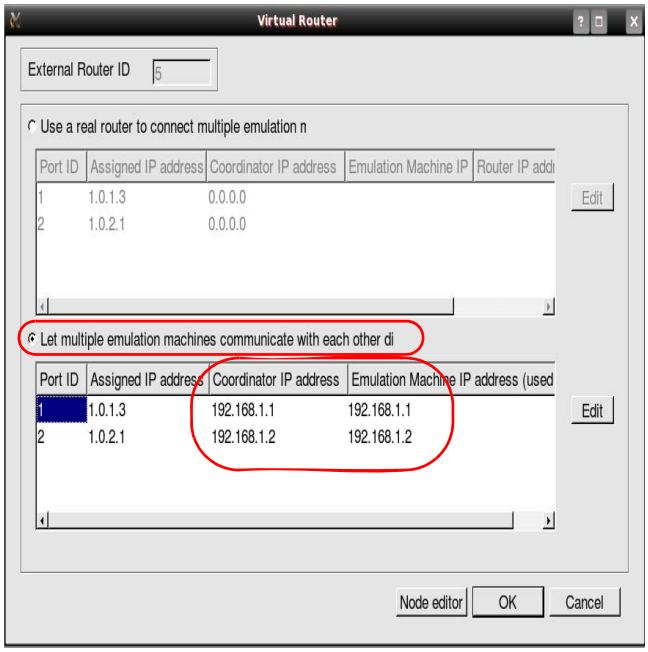
One should properly set the DISPATCHER_IP parameter of the coordinator.cfg file for each involved coordinator program. In this example, the DISPATCHER_IP should be set to 192.168.1.1 on each emulation machine so that each coordinator program will register itself with the same dispatcher program. After this is done, one should run up all coordinator programs on their respective emulation machines.

One then runs up the GUI program to draw the topology and set up the traffic. One should set the Dispatcher IP address for the GUI program in the **“Menu -> G_setting -> Dispatcher panel”.**

After finishing specifying the topology, one should double-click the icon of the virtual router to pop up its dialog box. In this example, because a virtual router corresponds to a layer-2 switch, one should enable the option “Let multile emulation machines communicate with each other directly.” The detailed setting for the two virtual routers are shown below. The first is for the virtual router on the left while the second is for the virtual router on the right.

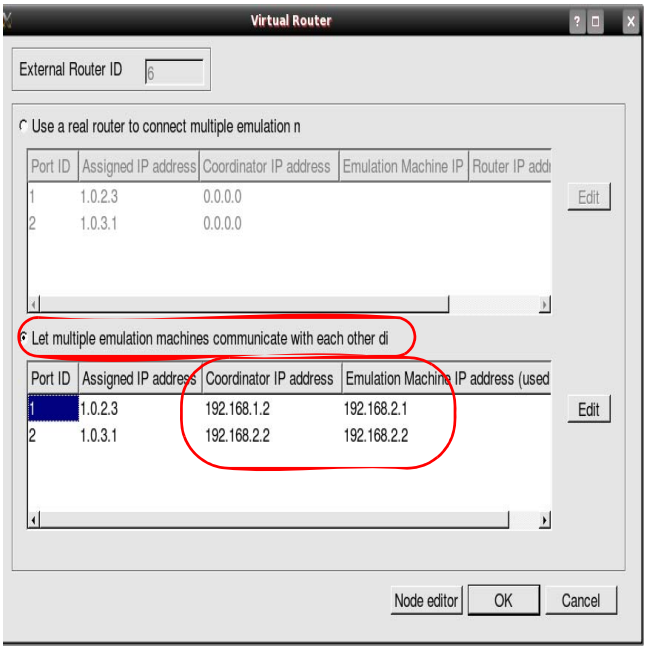
Notice port 2 in the dialog box of the left virtual router and port 1 in the dialog box of the right virtual router. Their **“Coordinator IP address”** fields should be set to 192.168.1.2. Their **“Emulation Machine IP address”** fields should be set to 192.168.1.2 and 192.168.2.1, respectively. The reasons for these settings are the same as those for the “**Use two real routers to connect emulation machines”** mode, which was explained previously.

After configuring the virtual routers, one can switch the GUI to the “Run Simulation” mode and start the distributed emulation.



Current Limitations

Although the distributed emulation approach used by NCTUns provides many advantages, it has several problems that remain to be solved. One is that the order of the timestamps of packet logs generated on different emulation machines may not accurately reflect the order of their occurrence in the real world. As a result, when they are merged together and played back on the packet animation player, the causal order of their appearance may be wrong. Another



problem is that this approach does not support the migration of a mobile node from one emulation machine to another. It is suggested that when one is designing how to partition a network for distributed emulation, one should choose a partition in which mobile nodes need not move from one part to another part of the emulated network.

To reduce the timing differencse among all involved emulation machines, it is recommended to synchronize the system clock of each emulation machine and those of the machines running the GUI, dispatcher, and coordinator programs. Before a distributed emulation case runs, the GUI program will send each coordinator program a control message to notify it of the time on which the emulation case should be started. If the system clocks of all involved machines are not accurately synchronized using the NTP protocol, the timing differences among them will be large, which will worsen the packet log timestamp causality problem discussed above.

Summary

This chapter shows the detailed steps to run a distributed emulation case. First, one should properly set the physical links to connect all emulation machines together according to the topology of the specified network. Then, one should properly configure the settings of the dispatcher program and that of each coordinator program running on different emulation machines. Finally, in the GUI program one needs to properly use the virtual routers to specify the partition points of the network topology before the distributed emulation case is started.

9. Mobile IP

Mobile IP protocol allows an infrastructure mode mobile host to leave its home network (subnet) and roam into a foreign (different) network (subnet) without breaking its current connections. NCTUns supports Mobile IP; including its basic scheme and the more advanced scheme called “route optimization.” We detail how to use Mobile IP protocol in this chapter.

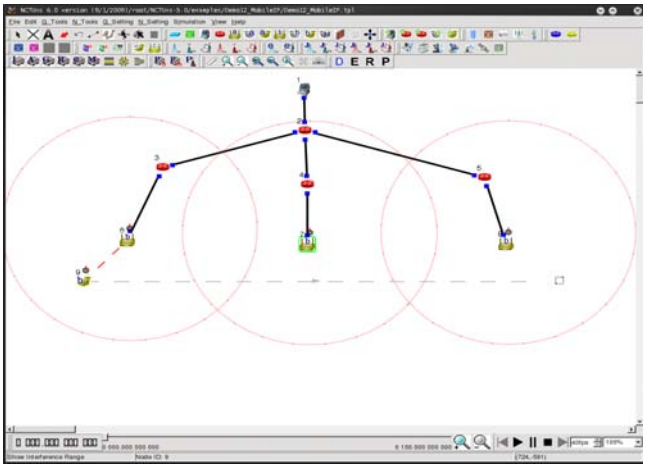
Mobile IP Concept

The entities involved in Mobile IP are mobile host, correspondent host, home agent, and foreign agent. Normally home agent and foreign agent programs run on routers and connections are created between the mobile host and the correspondent host (on the fixed network). The goal is to keep the connection when the mobile host leaves its home network and moves to a foreign subnet or when it moves from an old foreign network into a new foreign network. Readers should refer to relevant RFCs to get more information about Mobile IP.

A Mobile IP Usage Example

The following figure shows a Mobile IP usage example. In this network, there are three different wireless subnets located at the bottom. Each wireless subnet uses an IEEE 802.11 (b) access point to allow mobile hosts to get connected to the fixed network. Of course, making a connection is possible only if these mobile hosts are within the coverage area of the access point.

In this example, initially the infrastructure mode mobile host is in its home network, which is the wireless subnet on the left. A greedy TCP connection is created between it and the correspondent host at the top. Then it leaves its home subnet and moves toward the right access point. On its way, it will enter the wireless coverage area of the middle wireless subnet, and then that of the right wireless subnet. Then it will come back and return to its home network. With Mobile IP, the TCP connection can be kept alive continuously even though the mobile host has entered a different subnet with a different network number.

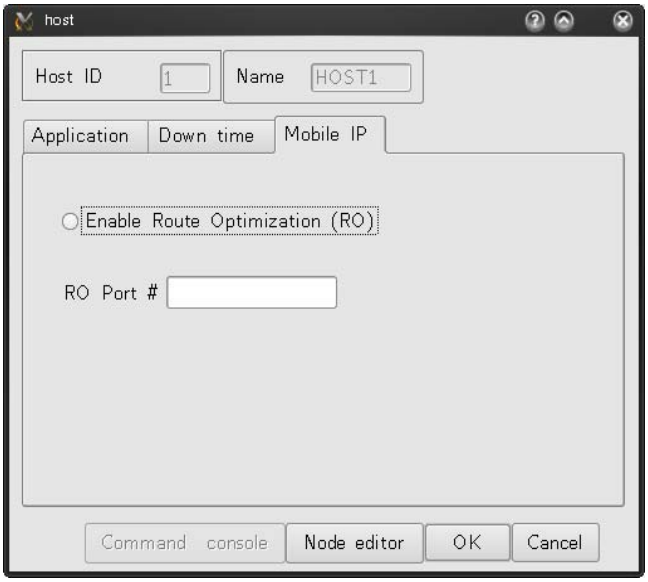


A mobile IP usage example.

Using Mobile IP

In the following, we show how to enable the Mobile IP function in NCTUns.

Correspondent Host



In the Mobile IP basic scheme the correspondent host need not do anything. However, if the correspondent host wants to use the more advanced “Route Optimization” scheme, the “Enable Route Optimization (RO)” option must be checked. Since an RO agent (daemon) needs to be run on this host, the

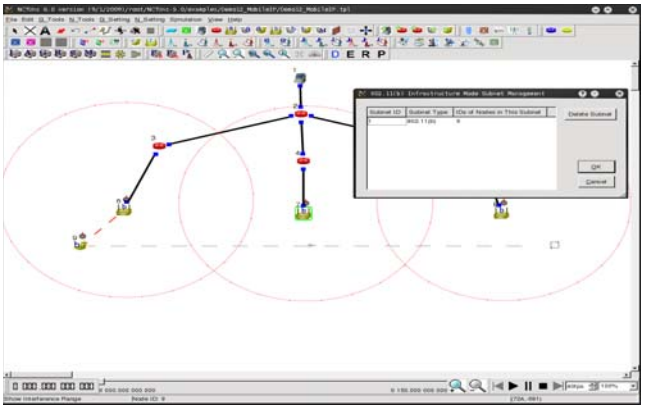
user must specify a UDP port number for this daemon. This port number should be different from all port numbers used by other daemons.

Infrastructure Mode Mobile Host

If the mobile host wants to use Mobile IP, the “Enable Mobile IP” option in the following figure needs to be checked. Also, the user needs to specify the IP address of the router where this mobile host’s home agent resides. Using the above example network to illustrate, the IP address here should be the IP address of the bottom interface of the left router. The user also needs to provide the IP address used by this mobile host to the mobile agent. This information is needed in the Mobile IP protocol because the mobile agent needs to register its own IP address with its home agent.

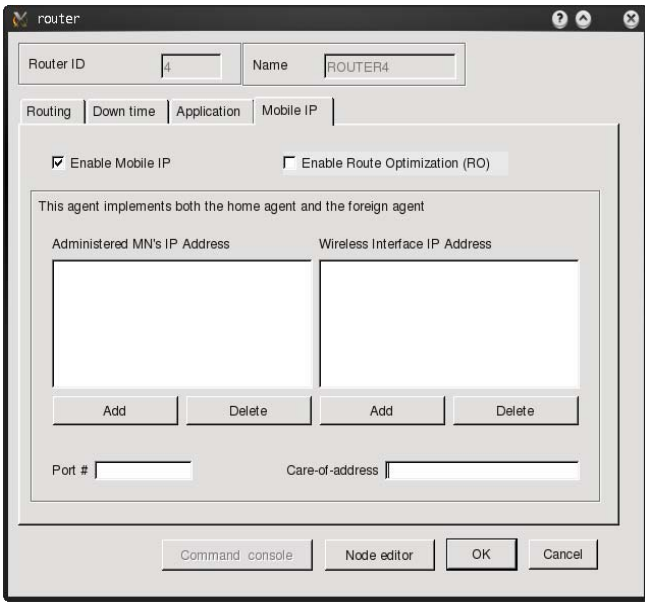
Form Wireless Subnet

After the mobile host is inserted, a user must use the “Form wireless subnet” ( ) tool to select it and the home IEEE 802.11(b) access point to group them together to form a wireless subnet. Specifying this relationship enables the GUI program to automatically assign IP and MAC addresses to the mobile host, saving much time and effort of the user. The subnet ID of the home subnet is automatically assigned by the GUI program and can be known by moving the mouse cursor over the blue interface box on the bottom side of the right most router. The formed wireless subnets can be viewed and managed by executing the **Menu -> N_Tools -> 802.11(b) Wireless Network -> Manage 802.11(b) Infrastructure Mode Subnets** command. The following figure shows the dialog box of this command.



Router

Routers are the places where the home agent and the foreign agent reside. In NCTUns, the functionality of a home agent and that of a foreign agent are combined together and implemented in a single agent program. That is, a router can act as both a home agent and a foreign agent at the same time.



For the functionality of the home agent on this router, a user needs to enter a list of IP addresses of mobile hosts which view this agent as their home agent. This information enables the home agent to know whether an administered mobile host has left its home network or has just returned back to its home network. The user also needs to specify a UDP port number for this home agent (daemon) to use. This port number should not be used by other daemon programs used in the simulation case.

For the functionality of the foreign agent on this router, a user must provide the IP address of an interface (on this router) that connects to a wireless access point. This setting tells the foreign agent to provide services on this specified wireless subnet. If this router has many interfaces each of which connecting to a different wireless access point and the user wants the foreign agent to provide services on all of these wireless subnets, he (she) can enter the IP addresses of all of these interfaces into this list.

The user then needs to specify the care-of-address used by this foreign agent. Normally it is the IP address of the network interface that is used by this router and goes toward the correspondent host.

Note that since the mobile IP agent running on a router implements both a home and a foreign agents, both the UDP port number used by the home agent and the care-of-address used by the foreign agent must be specified in this dialog box.

Finally, if the user wants to use the “Route Optimization” scheme on this router, this option needs to be checked.

Summary

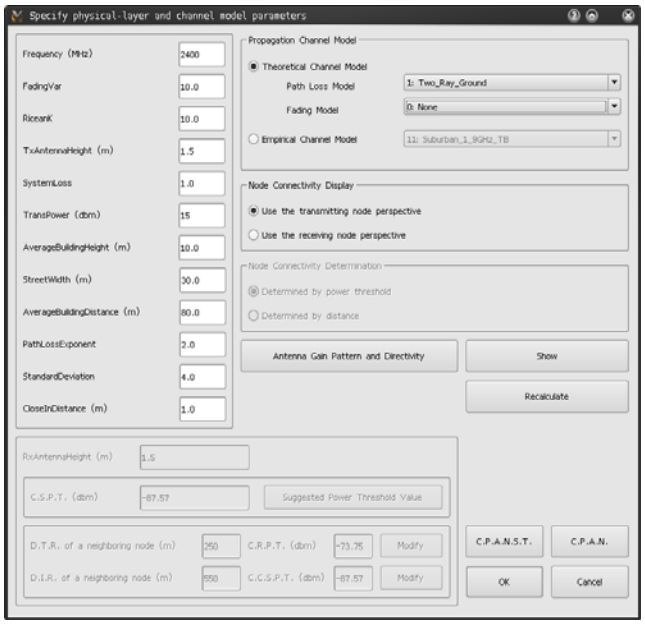
This chapter presents how to use Mobile IP in NCTUns. In NCTUns, Mobile IP is implemented as different agents (daemons) running on correspondent hosts, mobile hosts, and routers. Mobile IP allows a mobile host to maintain its connections when it enters a subnet different from its home subnet.

10. Physical Layer and Channel Model

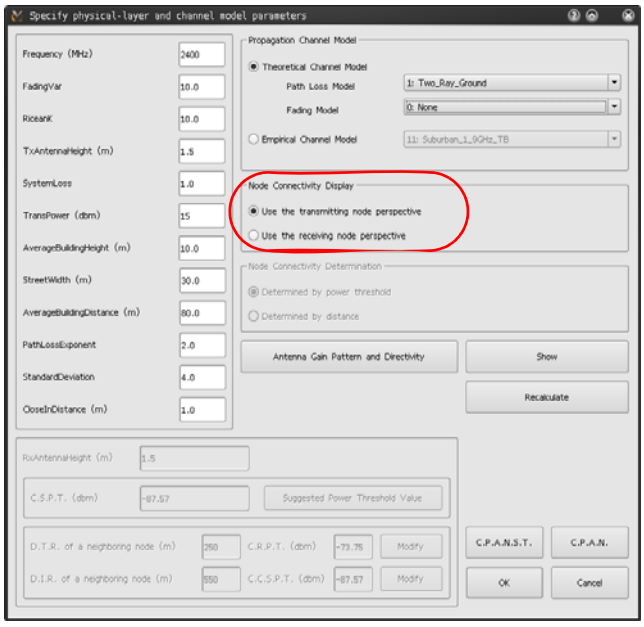
Physical layers and chanel models play important roles in realistic simulations of wireless networks. The tool "**Specify physical-layer and channel model parameters** ( )" is provided in NCTUns for users to specify the attributes of wireless physical-layer modules and the parameters of wireless channel models. This tool integrates all of the functions for setting the physical-layer and channel model parameters into a unified user interface, which includes the following components: 1) antenna attribute specification, 2) channel model specification, 3) connectivity calculation and display, and finally 4) antenna gain pattern and directivity specification. By coordinating the functions of these components, this tool can greatly save one's time and efforts required to specify a network case with sophisticated physical-layer setting. In this chapter, we explain the usage of this tool in detail.

Launching This Tool

To start this tool, one should first click the icon on the icon list panel, which is at the top the GUI program, and then click the icon of a wireless node that he/she intends to configure. After this is done, the following dialog box will pop up.



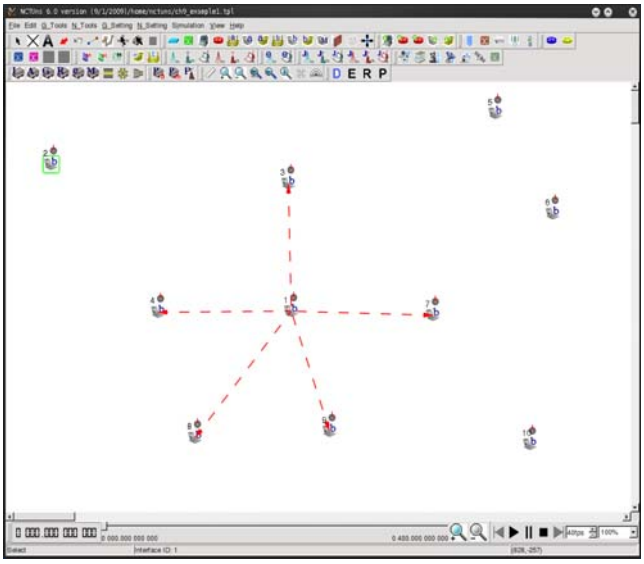
Before going into the detailed setting, we first explain the two modes provided by this tool to show node connectivity. Using the first mode, one can observe the radio connectivity of nodes from the perspective of a transmitting node, while using the second mode, one can observe the radio connectivity from the perspective of a receiving node. The difference between these two modes will be explained below soon. One can specify the node connectivity display mode in the **"Node Connectivity Display"** column, which provides two options: "**Use the transmitting node perspective**" and "**Use the receiving node perspective**." Choosing the former asks the nctunsclient program to display node connectivity from the transmitting node perspective, while choosing the latter asks it to display node connectivity from the receiving node perspective. The following figure shows the location of the **"Node Connectivity Display"** column.



Transmitting Node Perspective

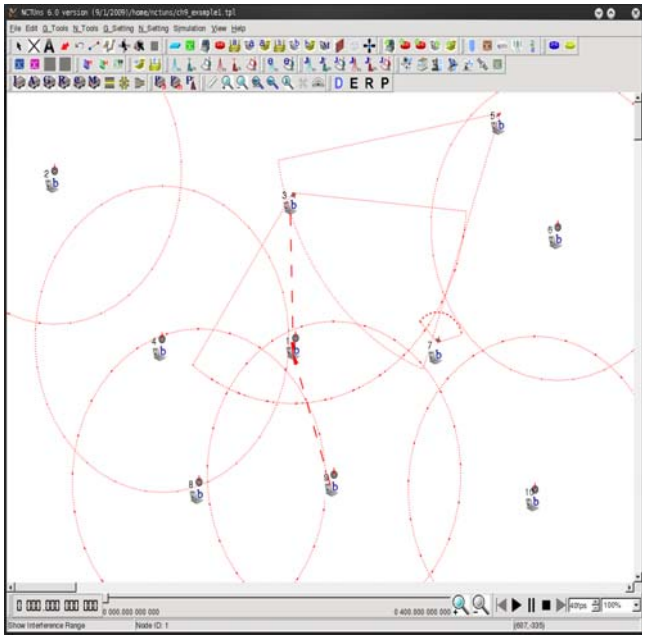
If the "**Use the transmitting node perspective**" mode is chosen, the GUI program will show which nodes will be interfered by the chosen node (the clicked node) in case it is transmitting a packet. This is accomplished by drawing a red-colored dotted arrow ( ) from the chosen node to a potentially-interfered node. Note that such an arrow from a node **X** to a node **Y** only indicates that node **Y** will be interfered by the node **X**'s packet transmission activity, which does not guarantee that node **Y** can successfully receive packets transmitted by node **X**. That is, node **Y** can sense node **X**'s packet transmission, which is likely to hinder node **Y**'s packet receiving activity, if they occur at the same time.

On the other hand, if node **X** intends to transmit a packet to node **Y**, node **Y** can sense this activity and start its receiving procedure to receive this packet. However, this does not necessarily mean that node **Y** can correctly receive the packet. The success of receiving node **X**'s packet is determined by many dynamic factors, e.g., the used modulation technology, the BER resulting from background noise, transmitting power, the adopted antenna gain pattern, etc. Since these factors can be dynamically changed during simulation, the GUI program cannot compute and display each node's effective transmission range when drawing a topology. (The effective transmission range of a node means that within it packets transmitted by the node can be successfully received by its 1-hop neighboring nodes, in case no packet collisions occur.) The following figure shows a snapshot when the "**Use the transmitting node perspective**" mode is used.



Receiving Node Perspective

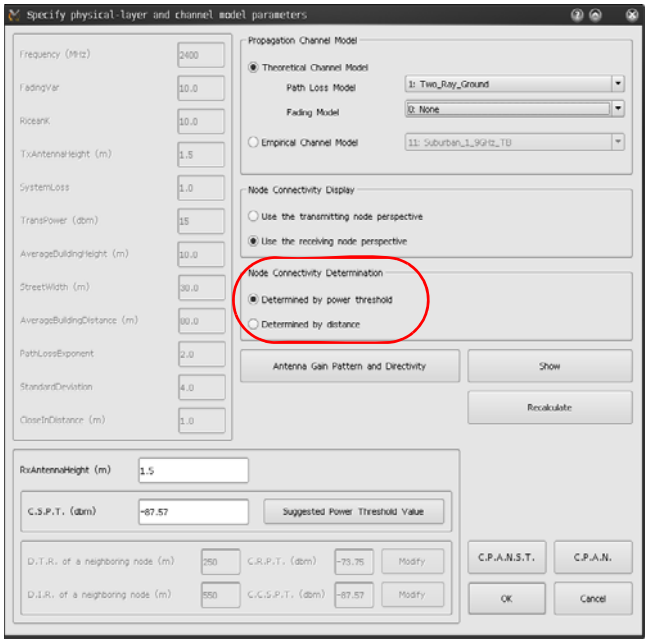
If the "**Use the receiving node perspective**" mode is chosen, the GUI program will show the maximum range that a node **X** can interfere with the chosen node, where node **X** denotes the set of nodes in the network other than the chosen node itself. In addition, if a node X can interfere with the chosen node using the current setting (Such setting includes the two nodes' current antenna settings, the distance between them, and the existence of obstacles on their line-of-sight path, etc.), the GUI program will draw a red-colored dotted arrow ( ) from node **X** to the chosen node, indicating that if the current setting is adopted, the transmission activity of node **X** can be sensed by the chosen node and may block the receiving activity of the chosen node. The following figure shows a snapshot when the "**Use the receiving node perspective**" mode is used.

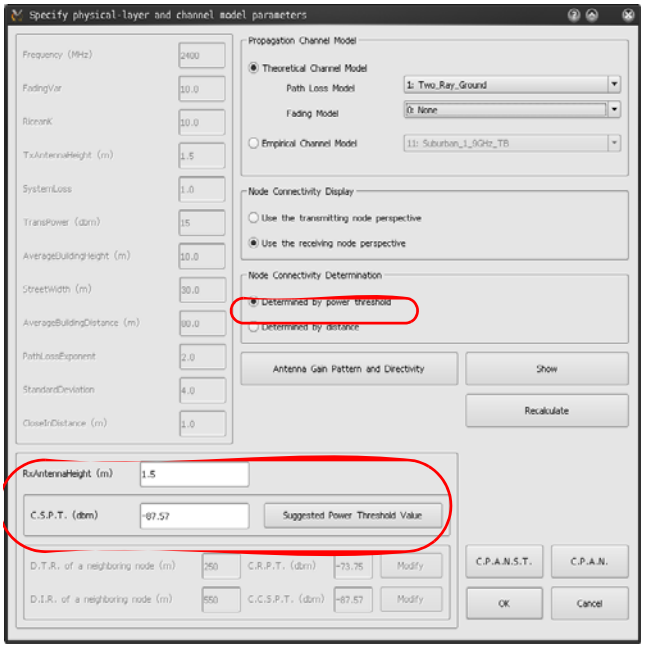


Node Connectivity Determination

When the "**Use the receiving node perspective**" mode is used, one can further choose the way that the GUI program uses to determine node connectivity. (The options in "**Node Connectivity Determination**" column are enabled only when the "**Use the receiving node perspective**" mode is used.) As shown in the following figure, there are two options in this column: 1) "**Determined by power threshold**" and 2) "**Determined by distance**."

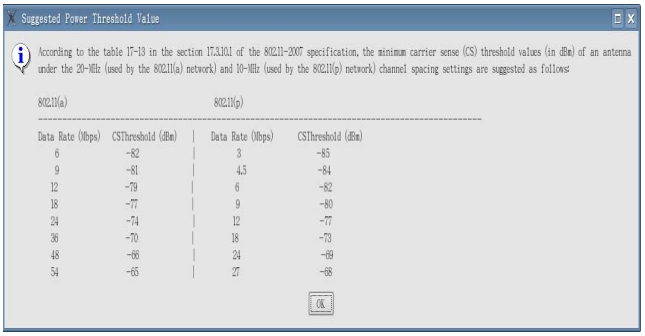
The former is the default option used by the GUI program. By choosing this option, the GUI program will determine node connectivity by comparing the receive power value obtained by a receiving node and a pre-defined receive power threshold value. The latter option is designed for routing modules that determines node connectivity by comparing nodes' distances and a pre-defined distance value, such as the GOD routing module. In the following, we explain the meanings of these two options in detail.





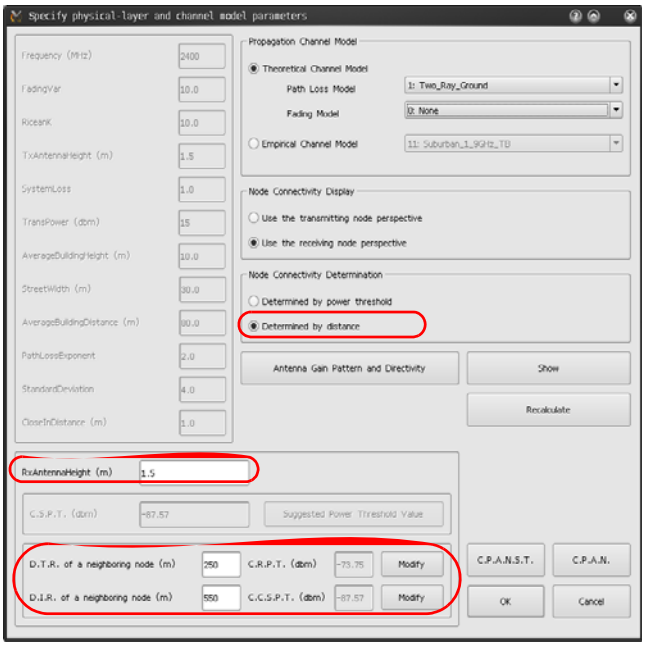
Recall that when the "**Use the receiving node perspective**" mode is used, the GUI program will calculate and show the maximum range that a node **X** can interfere with the chosen node, where node **X** denotes the set of nodes in the network other than the chosen node itself. As such, if the "**Determined by power threshold**" option is chosen, it means that NCTUns will calculate the interference range of each node **X** for the chosen node by comparing the calculated receive power value (transmitted by node **X)** on the chosen node and a user-defined **Carrier Sense Power Threshold (C.S.P.T.)** value. If the former is larger than the latter, it means that node **X** can interfere with the chosen node under the current setting. Otherwise, node **X** cannot interfere with the chosen node.

Note that, when using this node-connectivity determination mode, one is required to properly set the values of the "**RxAntennaHeight**" and "**C.S.P.T.** " parameters, so that the GUI program can automatically and correctly determine node connectivity. If one is not sure what values are suitable for the used network type, NCTUns lists suggested power threshold values for several networks that have strictly defined these values. One can click the "**Suggested Power Threshold Value**" button to show the suggested power threshold value table. The following two figures show where the values have to be set and the suggested power threshold value table, respectively.



On the other hand, if the "**Determined by distance**" option is selected, NCTUns will calculate the interference range of a node **X** for the chosen node based on the desired interference range (**DIR**). In addition, using this mode one can specify the desired transmission range (**DTR**) of each node **X** for the chosen node. The connectivity determination mechanism when using this mode is explained here. After specifying the DIR and DTR values, NCTUns will calculate their corresponding power threshold values using the current antenna and channel model setting. The power threshold value corresponding to DIR is called the corresponding carrier sense power threshold (**CCSPT**) and that corresponding to DTR is called the corresponding receive power threshold (**CRPT**). The former denotes that, under current antenna and channel model setting, the minimum value of the antenna power threshold that the chosen node should set, if it wants to sense the transmission activity of the node **X**. Similarly, the latter denotes, under the current antenna and channel model setting, the minimum value of the antenna power threshold that the chosen node should set, if it wants to correctly receive packets transmitted by node **X.**

After setting the DIR and DTR values, one can click "**Recalculate**" button to ask the GUI program to compute the CCSPT and CRPT values. The obtained CCSPT and CRPT values will be shown in the text fields of the bottom column. One can manually modify these two values to meet his/her own needs by clicking the **"Modify"** button. However, one should notice that, each time when the "Recalculate" button is pressed, the two values stored in the text fields will be automatically replaced by those derived from current antenna and channel model setting.

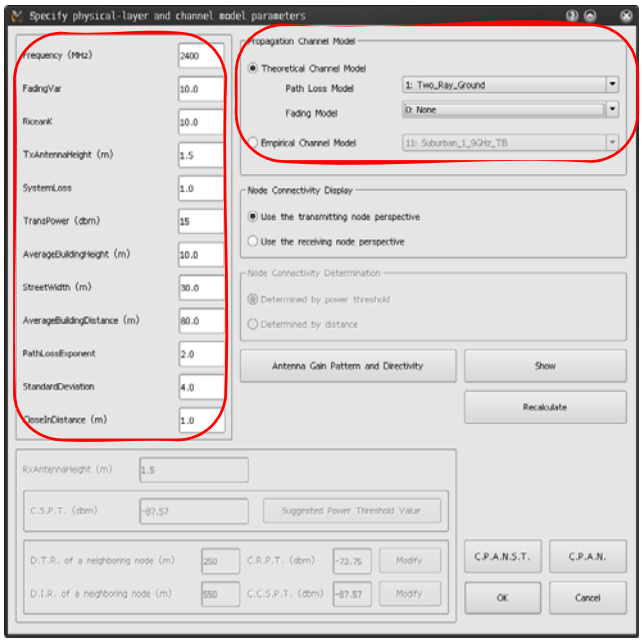


Antenna Parameter Setting

On the top-left of the dialog box is the antenna and channel model parameter setting column. One can set the values of antenna-related and channel-model-related parameters in this column, e.g., the operating frequency, the antenna height, and the transmitting power, etc.

Channel Model Selection

On the top-right of the dialog box is the channel model selection column. One can choose the signal propagation channel model that will be used in the simulation in this column. NCTUns categorizes the supported channel models into two classes. One is the "**Theoretical Channel Model**" class, which collects the channel models that are developed using theoretical formulas. In this class, one should first select the path-loss model that is intended to be used in the simulation and then can optionally select a collaborative fading model to more realistically simulate the fading effect.



Currently, NCTUns supports three theoretical path-loss models, which are listed as follows in sequence: "Free_Space," "Two_Ray_Ground," and "Free_Space_and_Shadowing" and three different fading models: "no-fading (None)," "Rayleigh Fading," and "Ricean Fading."

The other model class is the "**Empirical Channel Model**" class, which collects channel models that are developed based on real-life measurement results. So far, NCTUns supports 23 empirical channel models, e.g., "LEE_Microcell," "Okumura," "COST_231_Hata," and so forth. Users can choose one of them to simulate wireless channels by choosing the items shown in the list.

In addition to setting the channel model used in simulation here, alternatively one can choose and configure the used channel model via **Node Editor**. For context consistency, we do not present how to specify a channel using this approach here. Instead, we leave the introduction to this approach and more detailed information about a channel model in the next chapter.

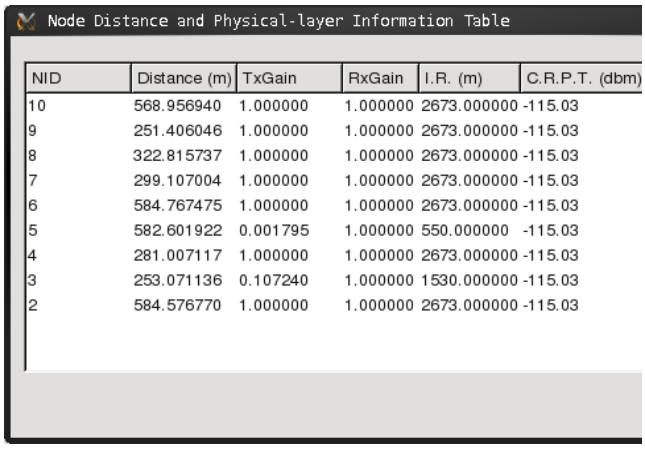
Recalculation and Display for Node Connectivity

After finishing configuring antenna and channel model settings, one can click the "**Recalculate**" button to ask the GUI program to perform the CRPT value calculation (when the "**Use the transmitting node perspective**" mode is chosen) or the CCSPT and CRPT value calculation (when the "**Use the receiving node perspective**" mode is chosen).

In addition, one can also click the "**Show**" button to show the **Node Distance and Physical-layer Information Table** (**NDPIT**). NDPIT shows the following information for users: 1) the distance between the chosen node and each other node; 2) the antenna gain values for each pair of nodes; 3) the interference range of each node from the perspective of the chosen node; and finally 4) the CRPT value of each node from the perspective of the chosen node.

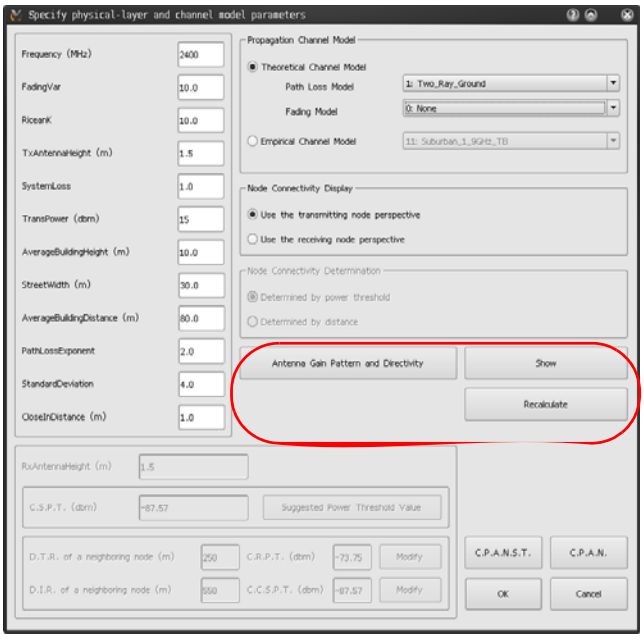
Note that the meanings of the 2nd, 3rd, and 4th items depend on whether the "**Use the transmitting node perspective**" mode is used or the "**Use the receiving node perspective**" mode is used. For example, suppose that the chosen node is node 1 and the first entry of NDPIT is for node 25. When the "**Use the transmitting node perspective**" mode is used, the *TxGain* value denotes the antenna gain value of the chosen node 1 and the *RxGain* value denotes the antenna gain value of node 25. On the other hand, when the "**Use the receiving node perspective**" mode is used, the *TxGain* value denotes the antenna gain value of node 25 and the *RxGain* value denotes the antenna gain value of the chosen node 1.

Similarly, when the "**Use the transmitting node perspective**" mode is used, the interference range denotes the maximum range that the chosen node 1 can interfere with node 25 and the CRPT value denotes the minimum power threshold value that node 25 should set, if it wants to be capable of sensing the transmission activity of node 1. In contrast, when the "**Use the receiving node perspective**" mode is used, the interference range denotes the maximum range that node 25 can interfere with node 1 and the CRPT value denotes the minimum power threshold value that node 1 should set, if it wants to be capable of sensing the transmission activity of node 25.

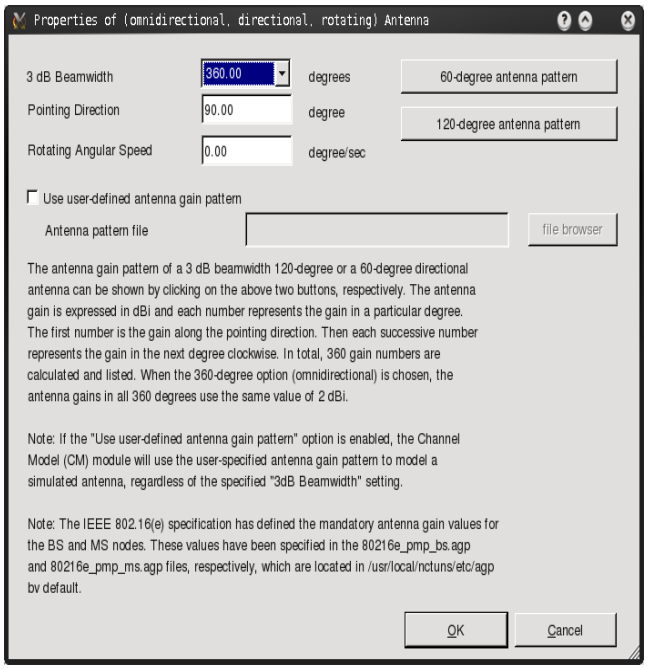


NID	Distance (m)	TxGain	RxGain	I.R. (m)	C.R.P.T. (dbm)
10	568.956940	1.000000	1.000000	2673.000000	-115.03
9	251.406046	1.000000	1.000000	2673.000000	-115.03
8	322.815737	1.000000	1.000000	2673.000000	-115.03
7	299.107004	1.000000	1.000000	2673.000000	-115.03
6	584.767475	1.000000	1.000000	2673.000000	-115.03
5	582.601922	0.001795	1.000000	550.000000	-115.03
4	281.007117	1.000000	1.000000	2673.000000	-115.03
3	253.071136	0.107240	1.000000	1530.000000	-115.03
2	584.576770	1.000000	1.000000	2673.000000	-115.03

Antenna Gain Pattern and Directivity



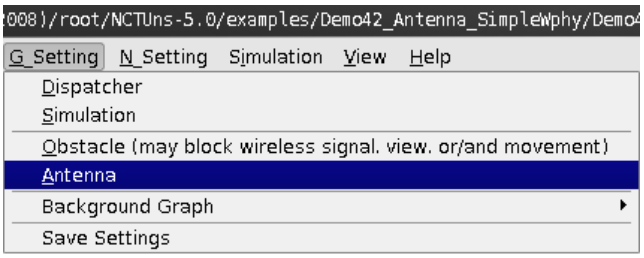
One can click the "**Antenna Gain Pattern and Directivity**" button to specify the gain pattern of a node's antenna and its directivity setting. The following figure shows the dialog box for configuring these two properties of an antenna.



In this dialog box, one can specify 1) the 3-dB beamwidth, 2) the orientation, 3) the rotating angular speed, and 4) the gain pattern of an antenna. The meanings of these attributes are explained in next section.

On the other hand, if one intends to configure the antenna properties of all nodes at the same time, one can use the "**Antenna**" tool to set up all nodes' antennas once. The

dialog box of the "**Antenna**" tool is the same as that shown in the above figure; however, the setting that one configures in its dialog box will be automatically applied to the antennas of all wireless nodes. The command path of the "**Antenna**" tool is "**Menu->G_Setting->Antenna**."



Directional Antenna Concept

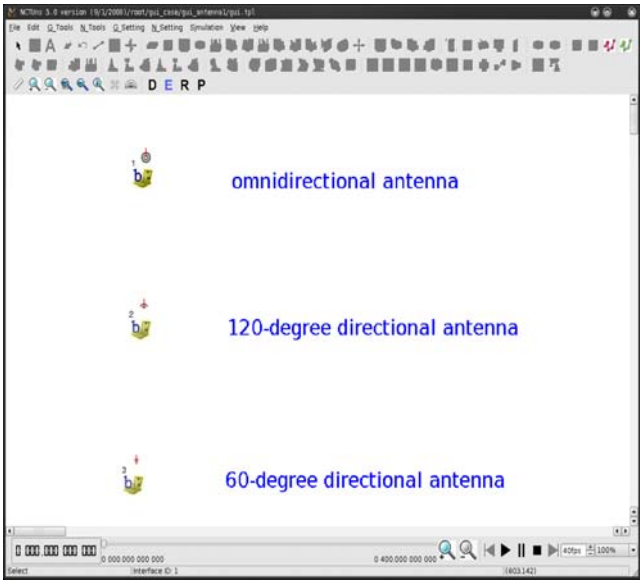
A directional antenna is an antenna that can generate different transmission gains in different directions and can generate higher gains in particular directions (so-called the main lobe). Due to this property, it can provide a longer transmission range and reduce signal interference in its neighborhood, as compared with an omni-directional antenna. When using a directional antenna for communication, the transmission/receiving direction of the antenna should be properly set to obtain a better gain, so that a better communication quality can be achieved.

One common way to describe the coverage of the main lobe for a directional antenna is using the 3-dB beamwidth value. The formal definition of the 3-dB beamwidth is exactly the (-3)-dB beamwidth, which is given as follows:

$$-3 = \log_{10}(p/p_{max}),$$

where $\mathbf{p_{max}}$ denotes the maximum power value achieved in the main lobe, and **p** denotes the power value achieved by the antenna at a specific angle. (Note that the **pmax** and **p** values are normalized to a reference power level generated by an omni-directional antenna.) According to this definition, the **p** value is approximately a half of the **pmax** value. As such, the (-3dB) beamwidth denotes the range of emission angles within which an antenna can generate transmission power (gain) that is at least half the maximum transmission power (gain) that it can generate.

The following figure shows the three default types of antennas supported by NCTUns: 1) omni-directional antenna; 2) 120-degree 3-dB beamwidth directional antenna; and 3) 60-degree 3-dB beamwidth directional antenna. As one sees, the circular radio wave icon denotes the antenna used by the node is omni-directional. In contrast, the 120-degree sectored radio wave icon and the 60-degree sectored radio wave icon denote the antennas used by the nodes are 120-degree and 60-degree, respectively, in terms of their 3-dB beamwidths.



When an omni-directional antenna is chosen, the antenna gains in all 360 degrees use the same value of 1, while when a sectored directional antenna is used, its gains over different degrees can vary greatly. NCTUns provides two example gain patterns for a 60-degree 3-dB beamwidth directional antenna and a 120-degree 3-dB beamwidth directional antenna, respectively. To show the detailed antenna gain value at each degree, one can click the button "**60-degree antenna pattern**" and "**120-degree antenna pattern**" in the dialog box. For users' convenience, we list the detailed gain values of these two gain patterns in all 360 degrees in the following [1].

In these two gain patterns, the antennas are assumed to point in the zero-degree direction, in which they generate the maximum gain values.

The Gain Pattern of the 60-degree Directional Antenna Provided by NCTUns

Degree	Gain (dBi)	Degree	Gain (dBi)
0	10.01294452	1/359	10.00975522
2/358	10.00018706	3/357	9.98423924
4/356	9.96191042	5/355	9.93319875
6/354	9.89810182	7/353	9.85661667
8/352	9.80873981	9/351	9.75446718

Degree	Gain (dBi)	Degree	Gain (dBi)
10/350	9.69379418	11/349	9.62671561
12/348	9.55322571	13/347	9.47331814
14/346	9.38698596	15/345	9.29422163
16/344	9.19501698	17/343	9.08936326
18/342	8.97725106	19/341	8.85867035
20/340	8.73361046	21/339	8.60206008
22/338	8.46400726	23/337	8.31943940
24/336	8.16834327	25/335	8.01070498
26/334	7.84651005	27/333	7.67574336
28/332	7.49838921	29/331	7.31443136
30/330	7.12385298	31/329	6.92663681
32/328	6.72276509	33/327	6.51221970
34/326	6.29498217	35/325	6.07103380
36/324	5.84035573	37/323	5.60292903
38/322	5.35873486	39/321	5.10775455
40/320	4.84996979	41/319	4.58536278
42/318	4.31391642	43/317	4.03561454
44/316	3.75044209	45/315	3.45838540
46/314	3.15943247	47/313	2.85357323
48/312	2.54079984	49/311	2.22110704
50/310	1.89449243	51/309	1.56095682
52/308	1.22050454	53/307	0.87314373
54/306	0.51888660	55/305	0.15774961
56/304	-0.21024640	57/303	-0.58507627
58/302	-0.96671075	59/301	-1.35511688
60/300	-1.75025882	61/299	-2.15209902
62/298	-2.56059997	63/297	-2.97572664
64/296	-3.39744986	65/295	-3.82575085
66/294	-4.26062725	67/293	-4.70210113
68/292	-5.15022937	69/291	-5.60511737
70/290	-6.06693667	71/289	-6.53594808
72/288	-7.01253175	73/287	-7.49722645
74/286	-7.99078140	75/285	-8.49422510
76/284	-9.00895785	77/283	-9.53687808
78/282	-10.08055809	79/281	-10.64349440
80/280	-11.23047450	81/279	-11.84813303
82/278	-12.50583056	83/277	-13.21711414

Degree	Gain (dBi)	Degree	Gain (dBi)
84/276	-14.00230068	85/275	-14.89342343
86/274	-15.94475128	87/273	-17.25871164
88/272	-19.06608410	89/271	-22.10439603
90/270	-166.66272129	91/269	-52.10439603
92/268	-49.06608410	93/267	-47.25871164
94/266	-45.94475128	95/265	-44.89342343
96/264	-44.00230068	97/263	-43.21711414
98/262	-42.50583056	99/261	-41.84813303
100/260	-41.23047450	101/259	-40.64349440
102/258	-40.08055809	103/257	-39.53687808
104/256	-39.00895785	105/255	-38.49422510
106/254	-37.99078140	107/253	-37.49722645
108/252	-37.01253175	109/251	-36.53594808
110/250	-36.06693667	111/249	-35.60511737
112/248	-35.15022937	113/247	-34.70210113
114/246	-34.26062725	115/245	-33.82575085
116/244	-33.39744986	117/243	-32.97572664
118/242	-32.56059997	119/241	-32.15209902
120/240	-31.75025882	121/239	-31.35511688
122/238	-30.96671075	123/237	-30.58507627
124/236	-30.21024640	125/235	-29.84225039
126/234	-29.48111340	127/233	-29.12685627
128/232	-28.77949546	129/231	-28.43904318
130/230	-28.10550757	131/229	-27.77889296
132/228	-27.45920016	133/227	-27.14642677
134/226	-26.84056753	135/225	-26.54161460
136/224	-26.24955791	137/223	-25.96438546
138/222	-25.68608358	139/221	-25.41463722
140/220	-25.15003021	141/219	-24.89224545
142/218	-24.64126514	143/217	-24.39707097
144/216	-24.15964427	145/215	-23.92896620
146/214	-23.70501783	147/213	-23.48778030
148/212	-23.27723491	149/211	-23.07336319
150/210	-22.87614702	151/209	-22.68556864
152/208	-22.50161079	153/207	-22.32425664
154/206	-22.15348995	155/205	-21.98929502
156/204	-21.83165673	157/203	-21.68056060

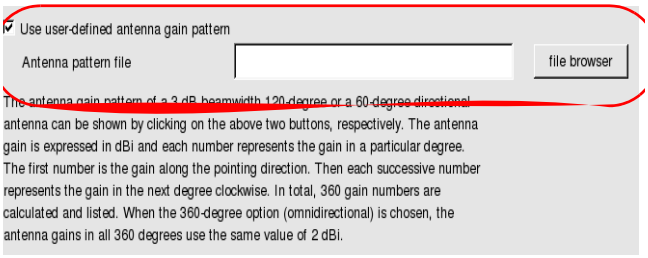
Degree	Gain (dBi)	Degree	Gain (dBi)
158/202	-21.53599274	159/201	-21.39793992
160/200	-21.26638954	161/199	-21.14132965
162/198	-21.02274894	163/197	-20.91063674
164/196	-20.80498302	165/195	-20.70577837
166/194	-20.61301404	167/193	-20.52668186
168/192	-20.44677429	169/191	-20.37328439
170/190	-20.30620582	171/189	-20.24553282
172/188	-20.19126019	173/187	-20.14338333
174/186	-20.10189818	175/185	-20.06680125
176/184	-20.03808958	177/183	-20.01576076
178/182	-19.99981294	179/181	-19.99024478
180	-19.98705548		

The Gain Pattern of the 120-degree Directional Antenna Provided by NCTUns

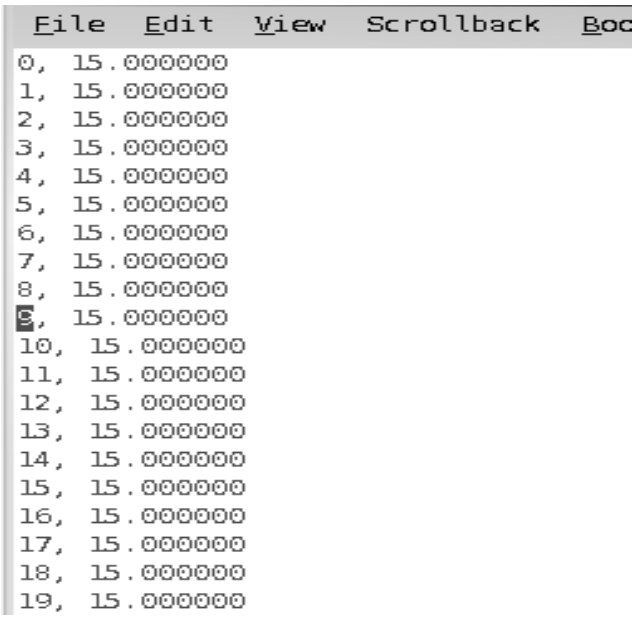
Degree	Gain (dBi)	Degree	Gain (dBi)
0	5.88539066	1/359	5.88472915
2/358	5.88274425	3/357	5.87943472
4/356	5.87479855	5/355	5.86883292
6/354	5.86153415	7/353	5.85289775
8/352	5.84291841	9/351	5.83158993
10/350	5.81890525	11/349	5.80485642
12/348	5.78943460	13/347	5.77262998
14/346	5.75443184	15/345	5.73482844
16/344	5.71380703	17/343	5.69135381
18/342	5.66745391	19/341	5.64209131
20/340	5.61524882	21/339	5.58690803
22/338	5.55704926	23/337	5.52565148
24/336	5.49269228	25/335	5.45814777
26/334	5.42199253	27/333	5.38419950
28/332	5.34473993	29/331	5.30358324
30/330	5.26069697	31/329	5.21604661
32/328	5.16959549	33/327	5.12130468
34/326	5.07113279	35/325	5.01903585
36/324	4.96496710	37/323	4.90887682
38/322	4.85071210	39/321	4.79041660
40/320	4.72793032	41/319	4.66318929
42/318	4.59612524	43/317	4.52666529
44/316	4.45473156	45/315	4.38024068
46/314	4.30310339	47/313	4.22322396
48/312	4.14049961	49/311	4.05481982
50/310	3.96606562	51/309	3.87410869
52/308	3.77881044	53/307	3.68002091
54/306	3.57757751	55/305	3.47130367
56/304	3.36100717	57/303	3.24647830
58/302	3.12748773	59/301	3.00378402
60/300	2.87509070	61/299	2.74110295
62/298	2.60148357	63/297	2.45585830
64/296	2.30381027	65/295	2.14487325
66/294	1.97852366	67/293	1.80417077
68/292	1.62114483	69/291	1.42868227
70/290	1.22590750	71/289	1.01180983
72/288	0.78521430	73/287	0.54474406
74/286	0.28877141	75/285	0.01535296
76/284	-0.27785758	77/283	-0.59372901
78/282	-0.93582024	79/281	-1.30862089
80/280	-1.71790704	81/279	-2.17128493
82/278	-2.67905630	83/277	-3.25566463
84/276	-3.92226369	85/275	-4.71164926
86/274	-5.67876416	87/273	-6.92660771
88/272	-8.68641770	89/271	-11.69605616
90/270	-156.24480078	91/269	-26.69605616
92/268	-23.68641770	93/267	-21.92660771
94/266	-20.67876416	95/265	-19.71164926
96/264	-18.92226369	97/263	-18.25566463
98/262	-17.67905630	99/261	-17.17128493
100/260	-16.71790704	101/259	-16.30862089
102/258	-15.93582024	103/257	-15.59372901
104/256	-15.27785758	105/255	-14.98464704
106/254	-14.71122859	107/253	-14.45525594
108/252	-14.21478570	109/251	-13.98819017
110/250	-13.77409250	111/249	-13.57131773
112/248	-13.37885517	113/247	-13.19582923

Degree	Gain (dBi)	Degree	Gain (dBi)
114/246	-13.02147634	115/245	-12.85512675
116/244	-12.69618973	117/243	-12.54414170
118/242	-12.39851643	119/241	-12.25889705
120/240	-12.12490930	121/239	-11.99621598
122/238	-11.87251227	123/237	-11.75352170
124/236	-11.63899283	125/235	-11.52869633
126/234	-11.42242249	127/233	-11.31997909
128/232	-11.22118956	129/231	-11.12589131
130/230	-11.03393438	131/229	-10.94518018
132/228	-10.85950039	133/227	-10.77677604
134/226	-10.69689661	135/225	-10.61975932
136/224	-10.54526844	137/223	-10.47333471
138/222	-10.40387476	139/221	-10.33681071
140/220	-10.27206968	141/219	-10.20958340
142/218	-10.14928790	143/217	-10.09112318
144/216	-10.03503290	145/215	-9.98096415
146/214	-9.92886721	147/213	-9.87869532
148/212	-9.83040451	149/211	-9.78395339
150/210	-9.73930303	151/209	-9.69641676
152/208	-9.65526007	153/207	-9.61580050
154/206	-9.57800747	155/205	-9.54185223
156/204	-9.50730772	157/203	-9.47434852
158/202	-9.44295074	159/201	-9.41309197
160/200	-9.38475118	161/199	-9.35790869
162/198	-9.33254609	163/197	-9.30864619
164/196	-9.28619297	165/195	-9.26517156
166/194	-9.24556816	167/193	-9.22737002
168/192	-9.21056540	169/191	-9.19514358
170/190	-9.18109475	171/189	-9.16841007
172/188	-9.15708159	173/187	-9.14710225
174/186	-9.13846585	175/185	-9.13116708
176/184	-9.12520145	177/183	-9.12056528
178/182	-9.11725575	179/181	-9.11527085
180	-9.11460934		

Besides using example antenna gain patterns, NCTUns allows users to conduct simulation using an arbitrary antenna gain pattern. To accomplish this, one should first turn on the "**Use user-defined antenna gain pattern**" option and then specify the path of his/her own antenna gain pattern file in the circled **"antenna pattern file"** field.



The format of an antenna gain pattern file (.agp file) is simple. Each line represents a gain value entry, which is composed of two fields separated by a comma. The former field denotes the degree of the antenna relative to its pointing direction, while the latter is the gain value of the antenna in dBi. The following figure shows an example of the .agp file.

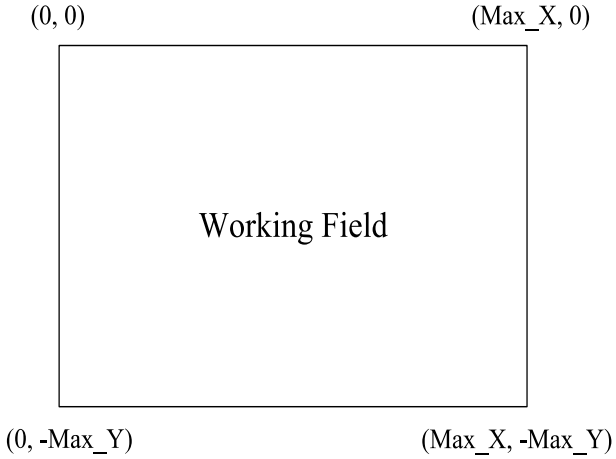


The format of the user-defined antenna gain pattern file

The Coordinate System for Antenna Directivity

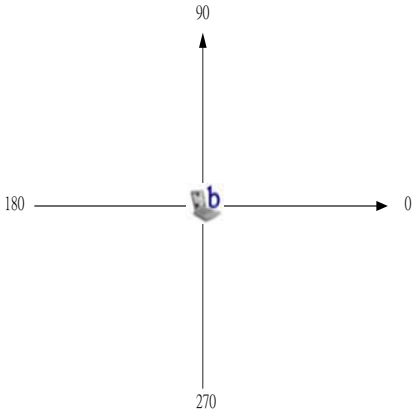
To correctly specify the directions of antennas, one should understand the coordinate system used by NCTUns and the representation of the working field in GUI. As shown in the following figure, NCTUns uses the **fourth quadrant** of the Cartesian coordinate system to represent the working field. The working field of NCTUns is represented by a rectangle, the apexes of which are listed, from the top-left to the bottom-left in the clockwise order, as follows: **(0, 0),**

(Max_X, 0), (Max_X, -Max_Y), and **(0, -Max_Y)**, where the Max_X denotes the maximum X-axis value of this rectangle and Max_Y denotes the maximum Y-axis value of this rectangle. In this coordinate system, the X-axis value increases from the left to the right and the Y-axis value increases from the bottom to the top, which is consistent with what we use in the daily life.



The reason why we do not use the common first quadrant of the Cartesian coordinate system to represent the working field is that the coordinate system used by the QT library (which is used by the GUI program to display a network topology) uses a coordinate system with the origin (0,0) at the top-left corner. The simplest way to convert this coordinate system to a common Cartesian coordinate system is mapping it onto the fourth quadrant of the common Cartesian coordinate system with the origin (0,0) on the bottom-left corner.

Based on this coordinate system, the polar coordinate system corresponding to it from a node's perspective is shown as follows.

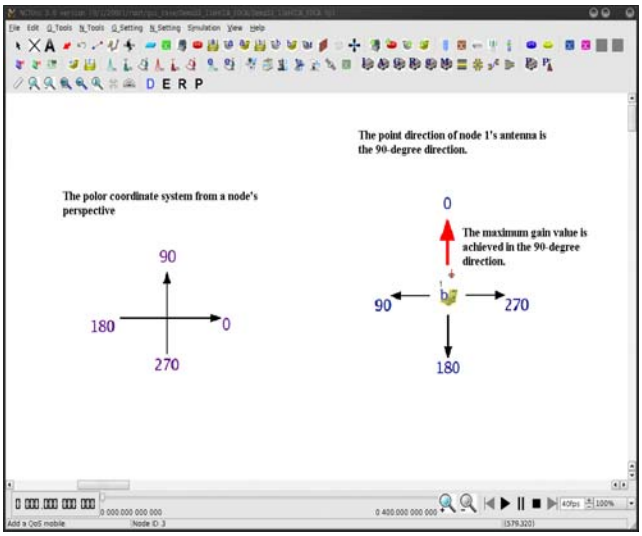


NCTUns uses this polar coordinate system to denote the antenna pointing direction of a node. In this polar coordinates, the horizontal line passing through the node itself towards the right denotes the zero-degree direction while that passing through the node towards the left denotes the 180-degree direction. On the other hand, the vertical line passing through the node towards the top denotes the 90-degree direction while that passing through the node towards the bottom denotes the 270-degree direction.

In the following, we use two examples to illustrate how the directivity of an antenna is represented in NCTUns. As one can see in the following figure, where there is an 802.11(b) mobile node equipped with a 120-degree directional antenna. Suppose that the node is now pointing its antenna towards the 90-degree direction. Using this setting, the antenna of this mobile node generates the maximum gain value in the 90-degree direction, meaning that the relative angle between the antenna pointing direction and the 90-degree direction is zero. As such, we can obtain the gain values over the 360 degrees by using the following transformation:

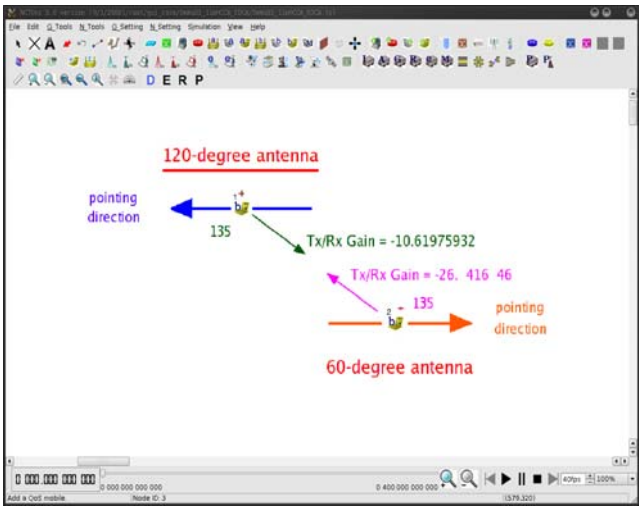
(Di,Gi) --> (((Di + Dpoint) mod 360), Gi),

where ***(Di,Gi)*** denotes the ***i-th*** entry of the antenna gain pattern file. In each entry, ***Di*** denotes the ***i-th*** degree of the antenna relative to its pointing direction and ***Gi*** denotes the gain value of the antenna in dBi at the ***i-th*** degree. ***Dpoint*** denotes the angle of the antenna's pointing direction.



The second example is shown in the following figure, where nodes 1 and 2 are equipped with the default 120-degree and 60-degree directional antennas provided by NCTUns, respectively. (The gain patterns of these two default directional antennas have been given previously.) The pointing

direction of node 1's antenna is 180 degree and that of node 2's is 0 degree. Under such a configuration, when node 1 transmits a packet to node 2, its antenna gain is -10.61975932 (called Transmission Gain) because the relative angle between its main transmission path and the antenna pointing direction is 135 degree. On the other hand, the antenna gain value of node 2 is -26.5416146 (called Reception Gain) because the relative angle between its main reception path and the antenna pointing direction is 135 degree.



The Copy of the Antenna Setting to All Nodes

After configuring an antenna, one can copy the setting of this antenna to those of all other nodes of the same (node) type by clicking "**C.P.A.N.S.T.**" button (denoting "**C**opy the **P**arameters to **A**ll **N**odes of the **S**ame **T**ype") and copy that to those of all other nodes containing the same physical-layer module by clicking the "**C.P.A.N**" button (denoting "**C**opy the **P**arameters to **A**ll **N**odes"). The locations of these two buttons are shown as follows.

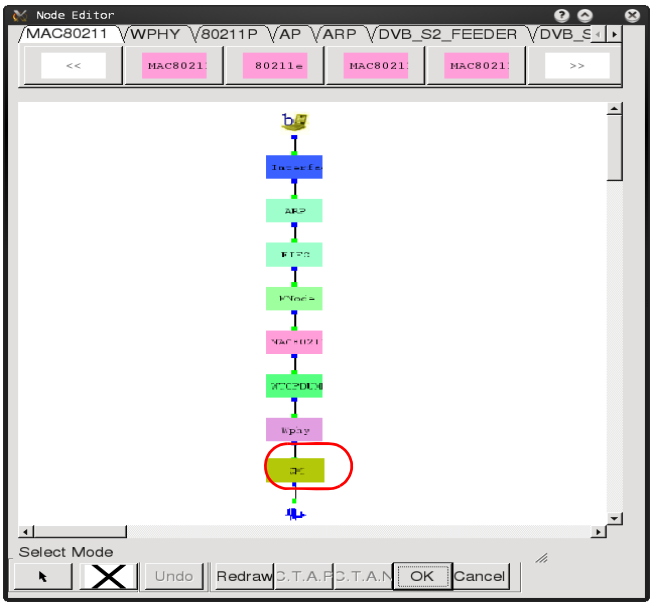
Using Node Editor to Configure Channel Models

Another approach to choosing and configuring a channel model and its parameters is by using **Node Editor**. In the following, we illustrate how to do this job.

Choosing and Setting the Used Channel Model via Node Editor

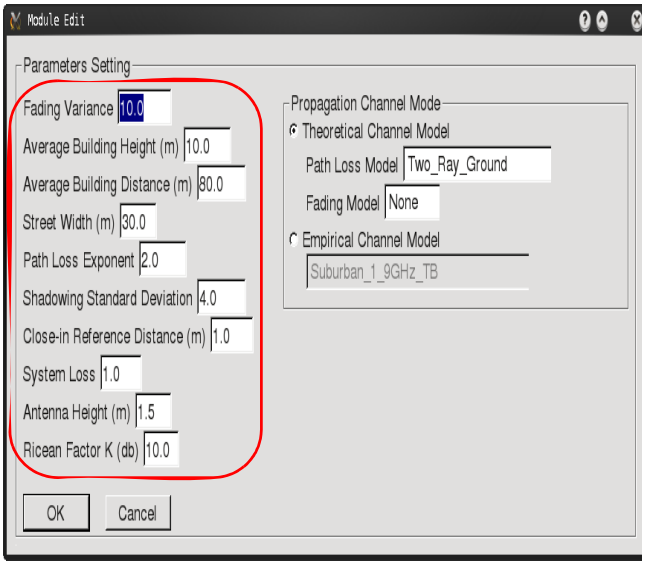
As one knows, the Node Editor can show all the protocol modules of a node. In NCTUns, every wireless node is forced to use the channel model (**CM**) module to simulate a wireless channel. The CM module provides plenty of wireless channel models that have been published and validated in the literature, which are helpful to increase simulation fidelity. In addition, it provides a unified and clear interface to service physical-layer modules of different wireless networks. As such, one can easily add a new channel model for a specific network type and hook up a channel model to a new network type.

The following figure shows the protocol stack of 802.11(b) infrastructure mode mobile node. The circled module is the CM module of this node.



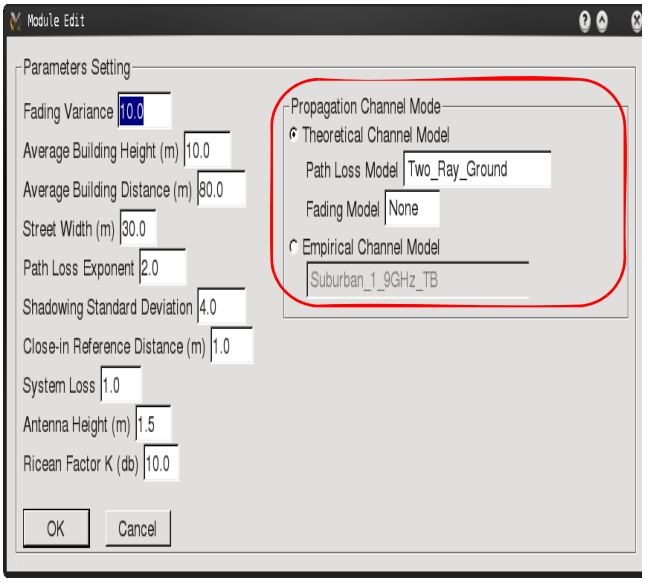
One can double-click the icon of the CM module to invoke the channel model setting dialog box shown as follows. On the left of the dialog box is the parameter setting generic to all of the channel models, such as fading variance, average building height, average building distance, street width, path loss exponent, shadowing standard deviation, close-in reference distance, system loss, antenna height, and ricean factor.

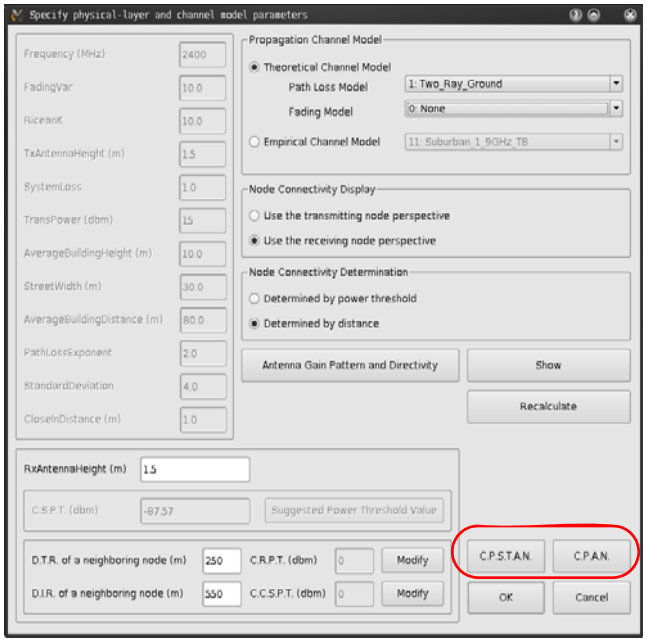
On the right of the dialog box is the channel model selection column. One can choose the signal propagation channel model that will be used in the simulation in this column. NCTUns categorizes the supported channel models into two classes. One is the "**Theoretical Channel Model**" class, which collects the channel models that are developed using theoretical formulas. In this class, one should first select the path-loss model that is intended to be used in the simulation and then can optionally select a collaborative fading model to more realistically simulate the fading effect. Currently, NCTUns supports three theoretical path-loss models, which



are listed as follows in sequence: "Free_Space," "Two_Ray_Ground," and "Free_Space_and_Shadowing" and three different fading models: "no-fading (None)," "Rayleigh Fading," and "Ricean Fading."

The other model class is the "**Empircal Channel Model**" class, which collects channel models that are developed based on real-life measurement results. So far, NCTUns supports 23 empirical channel models, e.g., "LEE_Microcell," "Okumura," "COST_231_Hata," and so forth. Users can choose one of them to simulate wireless channels by choosing the items shown in the list.





Summary

In this chapter, we explain the usage of the "**Specify physical-layer and channel model parameters** ( )" tool in detail. Via this tool, one can easily configure the properties of nodes' antennas, e.g., the operating frequency, the pointing direction, the gain pattern, the rotating speed, etc. NCTUns provides three typical antenna gain patterns and allows users to specify their own antenna gain patterns.

In addition to setting antennas' properties, using this tool one can easily choose the wireless channel model that should be used in simulation and fill in the parameters required by the chosen model. Another way is to use the node editor to choose a channel model and set its parameter values. NCTUns provides many different channel models. The detailed information about these models can be found in the source codes of the channel model (CM) module.

Reference

[1] Li-Chun Wang, Shi-Yen Huang, and Anderson Chen, "On the Throughput Performance of CSMA-based Wireless Local Area Network with Directional Antennas and Capture Effect: A Cross-layer Analytical Approach," IEEE WCNC, pp. 1879- 1884, Mar. 2004.

[2] NS-2 channel model,

"http://www.cse.msu.edu/~wangbo1/ns2/".

[3] Simon R. Saunders, Alejandro Aragon-Zavala, "Antennas and Propagation for Wireless Communication Systems," the 2nd edition, ISBN: 978-0-470-84879-1, Wiley, May, 2007.

[4] W.C.Y Lee and D.J.Y.Lee, “Microcell prediction in dense urban area,” IEEE Trans. Veh. Technol., vol.47, pp. 246-253, Feb. 1998.

[5] Okumura-Hata propagation prediction model for VHF and UHF range, in the “Prediction methods for the terrestrial land mobile service in the VHF and UHF bands” Rec. ITU-R P.529-3.

[6] Masaharu Hata, “Empirical Formula for Propagation Loss in Land Mobile Radio Services,” IEEE Transactions on Vehicular Technology, Vol29, No.3, pp.317-325, August 1980.

[7] V. S. Abhayawardhana, I. J. Wassell, D. Crosby, M. P. Sellars and M. G. Brown, “Comparison of Empirical Propagation Path Loss Models for Fixed Wireless Access Systems,” In Proc. of the IEEE Vehicular Technology Conference (VTC '05), Vol. 1, May 30-Jun 1, 2005, pp. 73-77, Stockholm, Sweden.

[8] V. Erceg et. al, “An empirically based path loss model for wireless channels in suburban environments,” IEEE JSAC, vol. 17, no. 7, July 1999, pp. 1205-1211.

[9] K. Konstantinou, “A Measurement-Based Model for Mobile-to-Mobile UMTS Links,” the IEEE 65th Vehicular Technology Conference 2007 (VTC2007-Spring), April 22-25, 2007, pp. 529-533, Dublin, Ireland.

[10] D.B.Green, M.S.Obaidat, “An Accurate Line of Sight Propagation Performance Model for Ad-Hoc 802.11 Wireless LAN (WLAN) Devices,” Proceedings of IEEE ICC 2002, New York, April 2002.

[11] Dongsoo Har, HowardH.Xia, Henry L. Bertoni, “Path-Loss Prediction Model for Microcells,” IEEE Transactions on Vehicular Technology, Vol. 48, No. 5, September 1999

[12] H. Xi, “A Simplified Analytical Model for predicting path loss in urban and suburban environments,” IEEE transactions on vehicular technology, vol. 46, pp. 1040-1046, 1997.

[13] Lim, J., Shin, Y. & Yook, J. “Experimanetal performance analysis of IEEE802.11a/b operating at 2.4 and 5.3 GHz,” proceedings of 10th Asia-Pacific conference on communications, 2004, pp. 133-136.

[14] B. Yesim HANCE and I. Hakki CAVDAR, “Mobile Radio Propagation Measurements and Tuning the Path Loss Model in Urban Areas at GSM-900 Band in Istanbul-Turkey,” IEEE Vehicular Technology Conference (VTC2004), pp. 139-143, Fall 2004.

[15] G. Y. Delisle, J. Lefevre, M. Lecours and J. Chouinard, “Propagation loss prediction: a comparative study with application to the mobile radio channel,” IEEE Transactions on Vehicular Technology, 26 (4), 295-308, 1985.

11. RTP/RTCP/SDP

Real time transport protocol (RTP), RTP control protocol (RTCP), and session description protocol (SDP) are commonly used to transport real-time traffic such as audio and video. This chapter illustrates how to use NCTUns to conduct RTP/RTCP/SDP simulations.

RTP/RTCP/SDP Concepts

RTP is a transport protocol for transporting real-time data such as audio and video. It can be used to provide the voice over IP (VoIP) service. RTP is composed of a data and a control component. The control component is called RTCP.

The data component of RTP is a simple protocol that provides support for real-time applications (e.g., an audio and/or video server). The support includes timing reconstruction, packet loss detection, data security, and other functions.

RTCP on the other hand provides support for real-time conferencing of groups. The support includes traffic source identification, audio/video gateways, multicast-to-unicast translators, and other functions. Traffic receivers can use RTCP to send quality-of-service feedback to the multicast group so that the traffic source's sending rate can be adjusted according to the current available bandwidth. RTCP also supports the synchronization of different media streams.

SDP is intended for describing multimedia sessions for the purposes of session announcement, session invitation, and other forms of multimedia session initiation. It provides a format for describing session information to session participants. Such information includes session-level parameters and media-level parameters. Session-level parameters may include the name of the session and media-level parameters may include the media type and format.

Because SDP provides only session descriptions and does not provide a way for transporting or announcing sessions, it needs to be used with other protocols such as the session initiation protocol (SIP). SIP is a signaling protocol that handles the setup, modification, and the tear-down of multimedia sessions. A common usage is that SIP contains SDP information within its message to set up or tear down multimedia sessions.

This chapter only gives a brief introduction to these protocols. More detailed information about RTP and RTCP can be found in [1, 2], more information about SDP can be found in [3], and more information about SIP can be found in [4].

RTP/RTCP Library and Example Programs

Unlike TCP, which is mostly implemented in the kernel of an operating system, RTP and RTCP protocols mostly are implemented in real-time application programs. In NCTUns, a RTP/RTCP library is provided so that an application program can easily use RTP and RTCP to transport real-time data. The binary and source files of this library are stored in the /lib/librtp directory of the package for the user's reference.

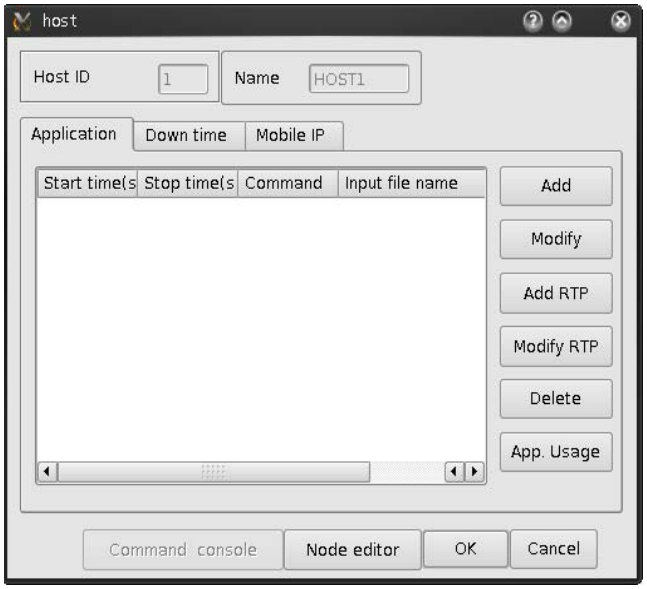
In addition to the RTP library, in NCTUns, three example application programs that use the RTP library are provided to demonstrate how to use the API functions provided by the RTP library. The names of these programs are rtprecvonly, rtpsendrecv, and adapt_bw, respectively. The differences between these programs are explained below. Rtprecvonly receives RTP and RTCP packets, sends RTCP packets, but does not send RTP packets. Rtpsendrecv sends and receives RTP and RTCP packets. The above two programs use a fixed rate to send their RTP packets based on the specified session bandwidth, selected media type, and the used codec scheme. On the other hand, adapt_bw uses RTCP packets to report the received quality-of-service at the receiver so that the sender can dynamically adjust the sending rate of its RTP packets.

In the dialog box of every host, a RTP command menu is provided for the user to quickly select one program from these programs. The source files of these programs are stored in the /tools/traffic-gen/rtp directory of the package for the user's reference. A user can reference these source files to understand how to use the provided RTP API. If a user wants to experiment a new way of using RTP, he (she) can change the source code of these programs and remake them. As long as the names of these programs are not changed, these newly-built RTP example programs will be used after they are copied to the default /usr/local/nctuns/tools directory.

Using RTP Example Programs

In the following, we illustrate how to run these RTP example programs in NCTUns simulations.

Since RTP programs typically are run on hosts and they have a large number of parameters, to save the user's time and effort, commands for automatically adding and modifying RTP application command strings are provided in the dialog box of a host. In the following figure, the "Add RTP" and "Modify RTP" buttons are provided for this purpose.

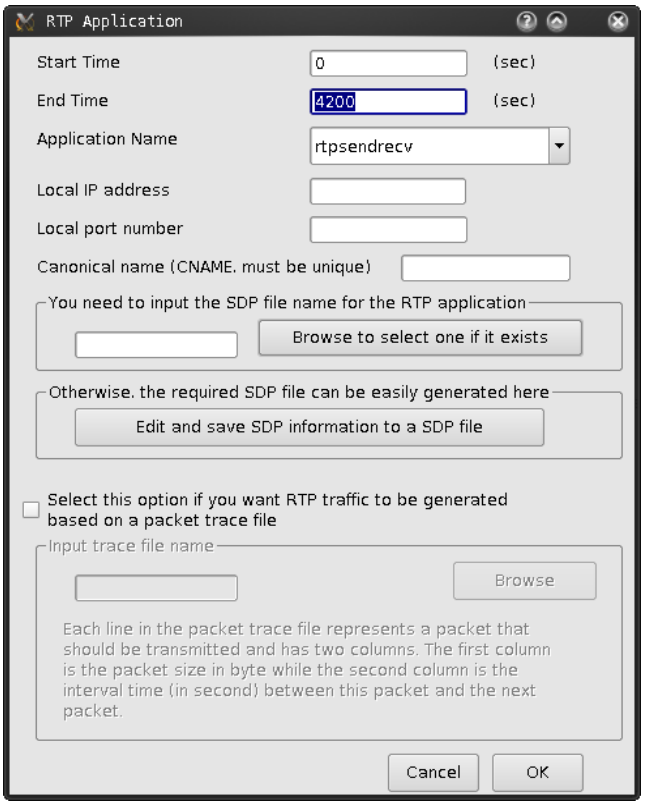


When a user clicks the "Add RTP" button, the following RTP dialog box will show up. In this dialog box, the user can set the start and end time of the RTP example program. One out of three RTP example programs can be selected from the "Application Name" command menu. The user then enters the IP address of this host into the "Local IP address" field and specifies an unused UDP port number for this RTP program. For the "Canonical name" field, the user needs to enter a unique name such as shieyuan@nctu.

Then the user needs to specify session and media-related parameters for the selected RTP program. These parameters should be stored in a SDP configuration file, which will be read by the selected RTP program. At this time, the user can click the "Edit and save SDP information to a SDP file" button to pop up the following SDP dialog box. If a SDP file exists and it can be modified for this RTP example program, the user can click the "Load" button to load its content for modification. Otherwise, the user will start with a blank SDP dialog box and later on save the entered SDP information into a SDP file.

Before a user clicks the "Edit and save SDP information to a SDP file" button, if a SDP file name has been specified in the SDP file name field (the one next to the "Browse to select one if it exists" button), its content will be loaded automatically for editing.

In the SDP dialog box, the Email and Phone number information can be omitted. The user needs to specify the bandwidth and active period of the session. On the left, a media-type menu is provided so that a user can easily select one media type without manually entering its associated parameter values. To understand the meanings of these media fields, the user should reference [5]. On the right, the user can enter the destination IP address(es) of RTP packets. If multiple IP addresses are entered, the RTP program on this host will use multiple unicast sessions to deliver RTP packets to each of these destination nodes.

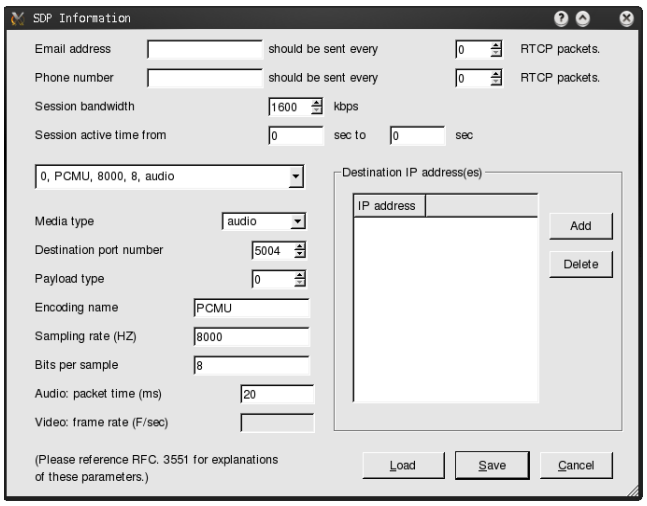


The RTP dialog box.

After all information has been entered into the SDP dialog box, the user can click the "Save" button to save these parameter values into a SDP file. The file name of this newly-created file (or the existing file) must be put into the "SDP file name" field so that the selected RTP program can

find and read it. Putting the SDP file name into this field can be done manually or via the “Browse to select one if it exists” button.

The rtpsendrecv example program uses a fixed rate to send its RTP packets. If a user wants this program to send out its RTP packets based on a packet trace file, he (she) can turn on the “Select packet trace file” option at the bottom of the RTP dialog box and select a file for it. The format of the packet trace file is simple. Each line in the packet trace file represents a packet that should be transmitted and has two columns. The first column is the packet size in byte while the second column is the interval time (which is in second and can be less than 1 such as 0.01) between this packet and the next packet. This option is useful for transferring a real-world media file such as a MPEG-2 movie stream over a simulated network.



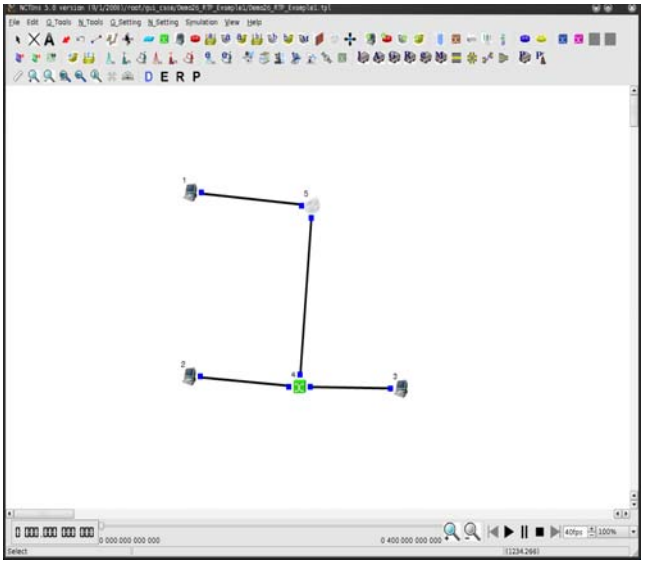
The SDP dialog box.

An Example

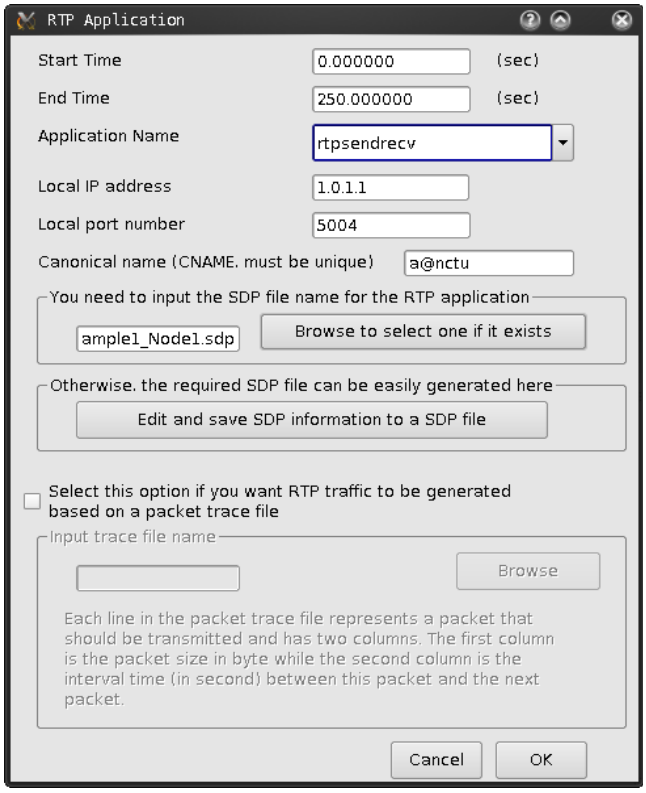
We use an example to illustrate the uses of RTP, RTCP, and SDP in NCTUns. In the following figure, host1 and host2 are both a RTP sender and receiver while host3 is only a RTP receiver. That is, host1 sends RTP packets to both host2 and host3, host2 sends RTP packets to both host1 and host3, but host3 does not send any RTP packets to host1 and host2.

The packet loss rate configured on WAN for the direction from host 1 to host 2 (and host 3) is 10% while the packet loss rate configured on WAN for the reverse direction is 5%. The RTP programs run on host1, host2, and host3 use RTCP to report the measured (1) round-trip-time (RTT) of packets, (2) delay jitter of packets, (3) loss rate of packets, and (4) cumulative number of lost packets between a pair of hosts. These information are generated by these RTP programs and saved into log files with the following names IP(i)-IP(j)-IP(k).delay, IP(i)-IP(j)-IP(k).jitter, IP(i)-IP(j)-IP(k). pktlossrate, IP(i)-IP(j)-IP(k).pktlost, respectively.

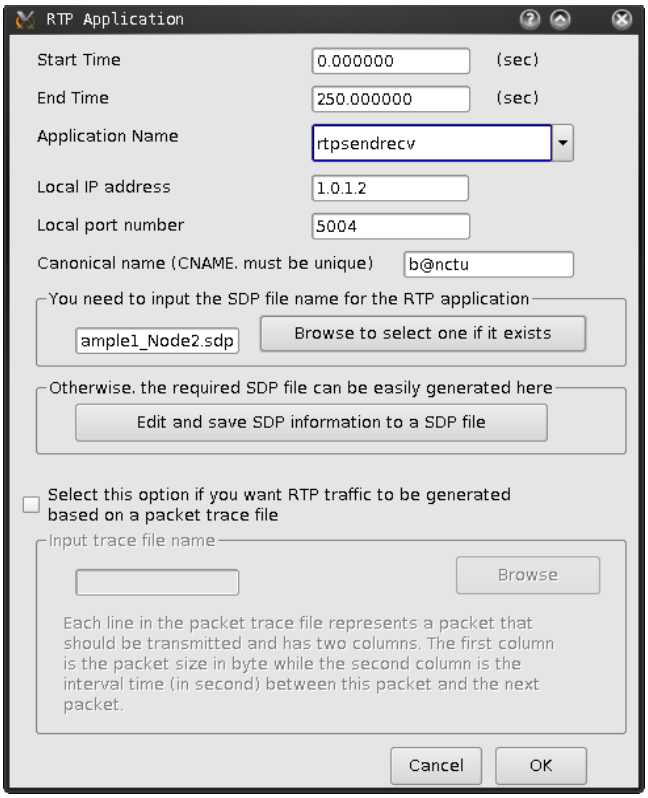
In the above filename IP(i)-IP(j)-IP(k), IP(i), IP(j), and IP(k) will be replaced with the IP address of host(i), host(j), and host(k) in the simulated network, respectively. This file name means that the logged performance (e.g., delay, jitter, loss rate, or lost number) are the measured performance of the packets exchanged between host(i) and host(j) and reported by host(k). A user can see these RTP log files to check whether the packet loss rates reported by RTCP are consistent with the WAN’s packet loss rate settings.



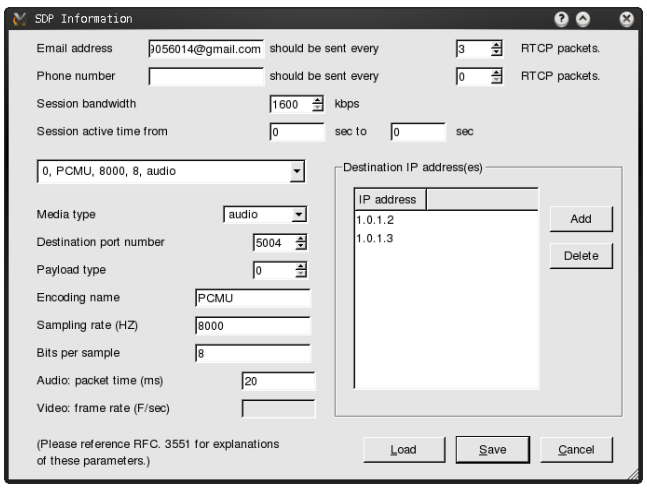
In the following, we show the RTP and SDP settings for host1, host2, and host3, respectively. In this example, the SDP setting for host(i) is stored in a file named XXX_Node(i).sdp and this file name must be entered into the RTP dialog box of host(i), where i = 1, 2, and 3.



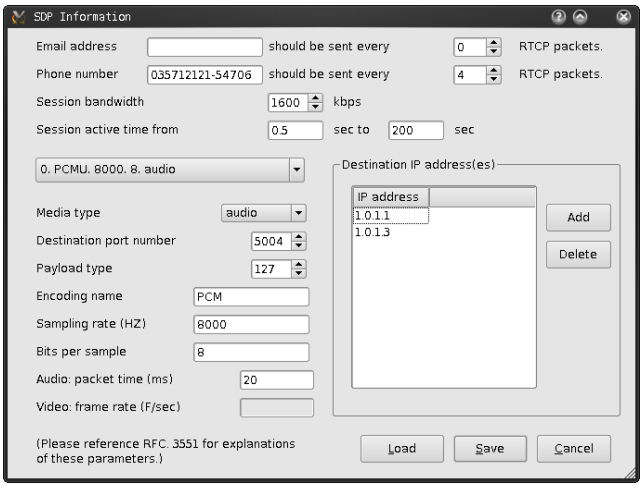
Host1's RTP dialog box.



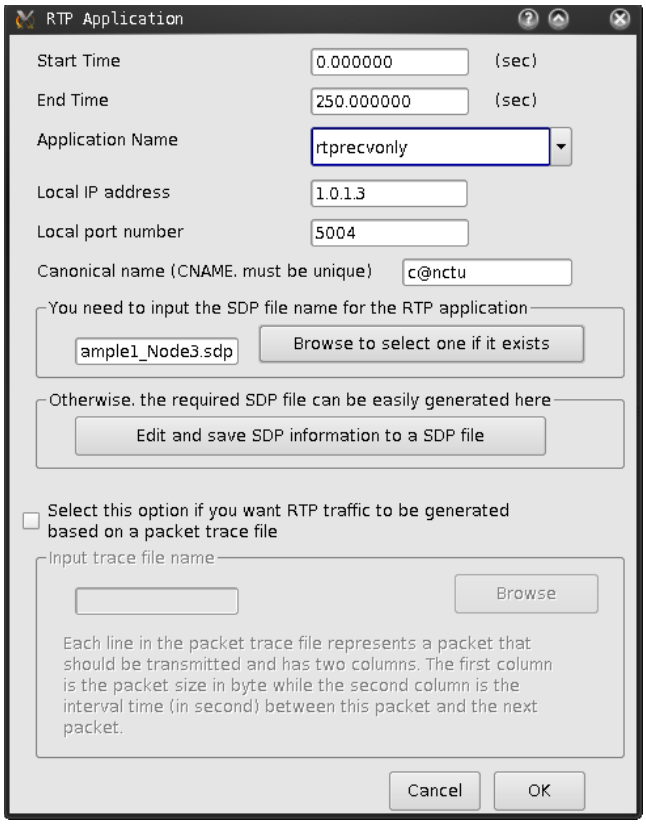
Host2's RTP dialog box.



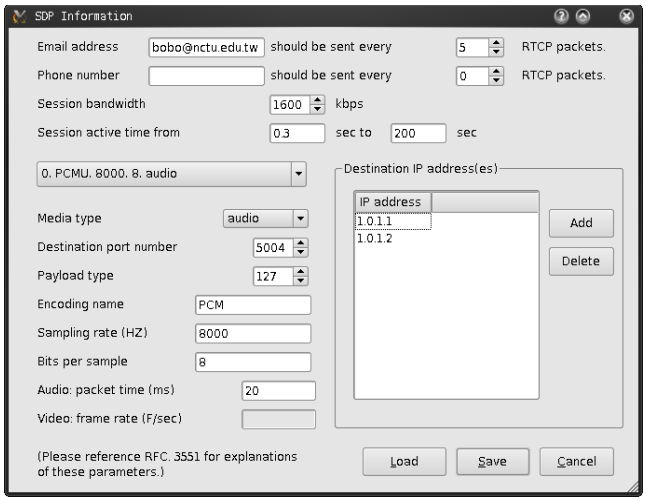
Host1's SDP dialog box.



Host2's SDP dialog box.



Host3's RTP dialog box.



Host3's SDP dialog box.

Summary

This chapter presents how to use RTP, RTCP, and SDP in NCTUns. In the NCTUns, RTP and RTCP are implemented as a user-level library whose API functions can be directly called by a user-level application program. NCTUns provides three RTP example programs that use the provided RTP library. A user can study their source code to learn how to use the RTP library to make his (her) own RTP application programs.

Reference

[1] RFC 1889, "RTP: A Transport Protocol for Real-Time Application."

[2] RFC 1890, "RTP Profile for Audio and Video Conferences with Minimal Control."

[3] RFC 2327, "SDP: Session Description Protocol."

[4] RFC 2543, "SIP: Session Initiation Protocol."

[5] RFC 3551, "RTP Profile for Audio and Video Conference with Minimal Control."

12. GPRS Networks

General packet radio service (GPRS) uses the existing GSM cellular network to provide wide-area end-to-end packet switched services. The wireless range of a GPRS base station can be up to 35 Km but the provided data rate for a 3+1 (downlink/uplink time slots) GPRS user is only about 36/12 Kbps for the downlink and uplink directions. In this chapter, we illustrate how to use NCTUns to conduct GPRS simulations.

GPRS Concept

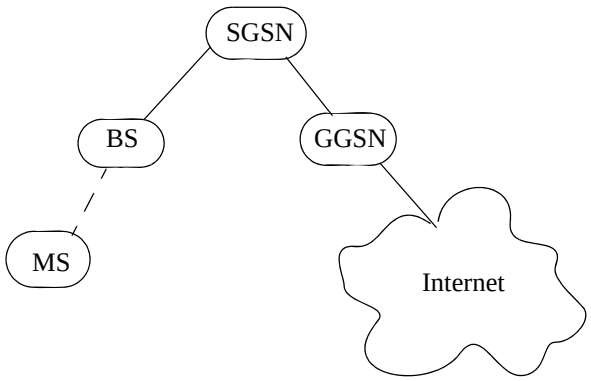
GPRS is provided on the existing GSM cellular networks to provide wide-area data services. A user can use GPRS to connect to the Internet for browsing web pages, checking email, downloading files, receiving/sending important messages when he (she) is away from his (her) office and home networks. Because the coverage area of a GPRS base station can be very large (the radius of the coverage area can be any number from 1 Km up to 35 Km), the data applications enabled by GPRS are well suited for users who are on moving vehicles or away from fixed networks.

In a GSM/GPRS cell, GSM voice traffic competes with GPRS data traffic for the channel bandwidth provided by the GSM/GPRS base station. Normally, a base station is assigned the same number of frequency channels for its downlink and uplink traffic, respectively. That is, if a base station is allocated 10 frequency channels, it will have 10 channels in the uplink band and another 10 channels in the corresponding downlink band. Using the TDMA scheme, each channel is divided into time slots and 8 TDMA channels are formed by these time slots. That is, if we make 8 consecutive time slots as a group, then the Nth time slot in every group are used for the Nth TDMA channel, where N = 1, 2, .., 8. A GSM user uses a download and uplink TDMA channels for his (her) voice traffic during the entire call period. The time slots of these TDMA channels cannot be used by other users even though the user has no voice traffic to send.

A GPRS user normally is allocated 3 time slots and 1 time slot for his (her) downlink and uplink traffic, respectively. (This service profile is typically called the 3+1 package.) The time slots allocated to a GPRS user can be dynamically used by other GSM or GPRS users when they are not used by the user. Using the CS2 coding scheme, in which one time slot corresponds to 12 Kbps bandwidth, a 3+1 GPRS user can receive 36 Kbps and 12 Kbps for the downlink and uplink directions, respectively. These numbers represent the optimal throughputs that may be achieved under ideal channel conditions. In reality, the measured numbers are usually less than these ideal numbers due to poor channel quality and inadequate time slots allocated to GPRS traffic.

GPRS Network Architecture

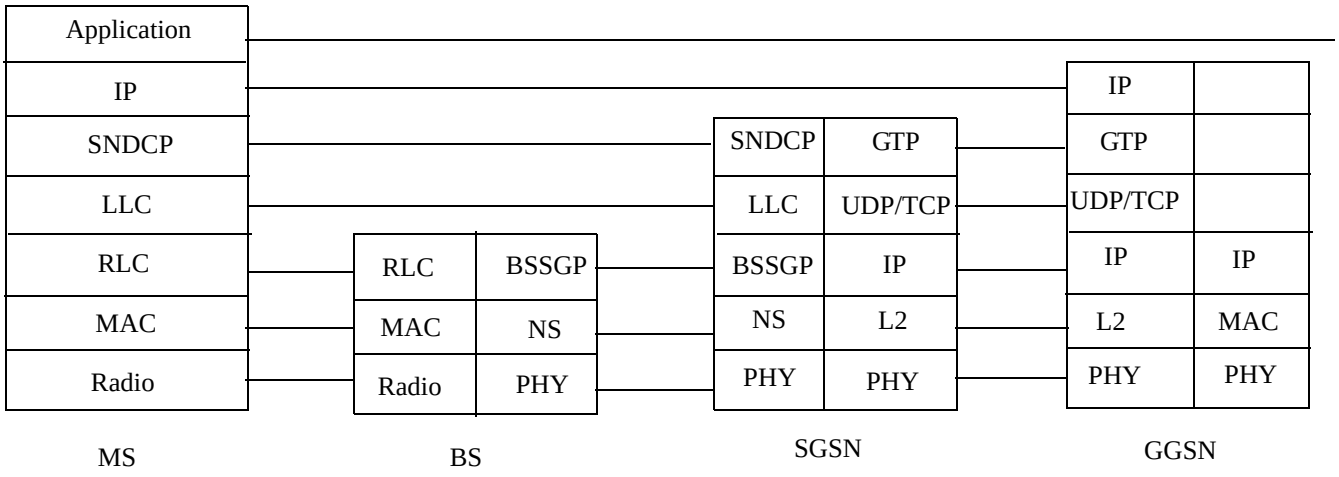
A GPRS network is composed of GPRS phones (MS), GPRS base stations (BS), serving GPRS support nodes (SGSN), and gateway GPRS support nodes (GGSN). SGSN in GPRS is equivalent to Mobile Switching Center (MSC) in GSM networks. GGSN provides interworking between a GPRS network and an external packet-switched network such as the Internet. SGSN is connected with GGSN via an IP-based GPRS backbone network. The architecture of a GPRS network is depicted in the following figure.



GPRS network architecture.

GPRS Protocol Stack

The protocol stacks used in GPRS devices are depicted in the following figure. The full names of these protocols are described as follows. SNDCP: SubNetwork Dependent Convergence, LLC: Logical Link Control, RLC: Radio Link Control, MAC: Medium Access Control, Radio: Radio Physical Layer, BSSGP: BSS GPRS Protocol, NS: Network Service, GTP: GPRS Tunneling Protocol, L2 is any layer-2 (data link layer) protocol such as Frame Relay or ATM.



GPRS protocol stack.

In NCTUns, these protocols are implemented as protocol modules. To understand the details of these protocols, readers may reference [1, 2].

There are some differences between a real-world GPRS network protocol stack implementation and a NCTUns GPRS network protocol stack implementation. The first difference is that a GPRS phone (MS) in NCTUns has a TCP/UDP protocol layer in its protocol stack while a GPRS phone in the real world does not have one. In NCTUns, because internally a GPRS phone plays the same role as a host, the TCP/UDP and IP layers of a GPRS phone's protocol stack are the simulation machine's real-world TCP/UDP/IP implementation. Also, any real-world application program can run on a GPRS phone, just like being run on a host. These capabilities are beyond the capabilities of current GPRS phones in the real world and may only be possible on 3G or 4G phones.

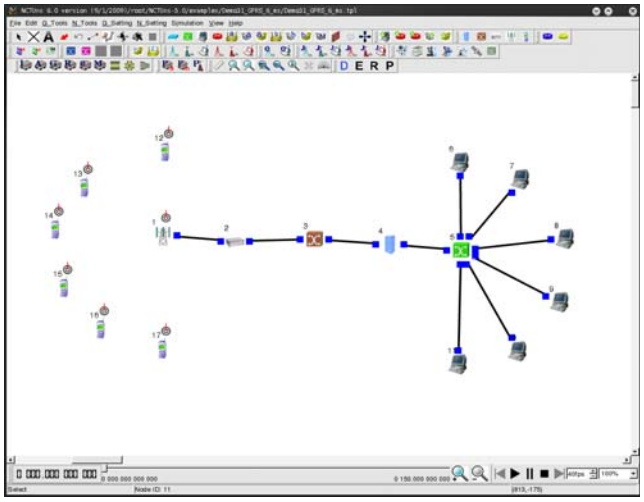
The second difference is that in NCTUns a pseudo device named "GPRS switch" must be used to connect a SGSN with a GGSN while in the real world it is unnecessary. This design decision is based on the fact that multiple GPRS tunnels may exist between multiple SGSNs and multiple GGSNs. To let the IP addresses of the endpoints of these GPRS tunnels share the same subnet ID for easy management, NCTUns GUI enforces that a "GPRS switch" must be used to connect a SGSN with a GGSN even if only a pair of SGSN and GGSN exists in the simulated GPRS network. Note that the "GPRS switch" is just a device used in the GUI to enforce such a connectivity. Actually it does not exist in the exported .tcl file. That is, there is no such a device in a GPRS simulation execution. Instead, the packets of a GRPS tunnel are delivered from one end to the other end "immediately" without simulating the delay and bandwidth of the underlying physical links. Effectively, we can view that the simulated link delay is 0 and the simulated link bandwidth is infinite for the link between SGSN and GGSN. Although this settings may be different from the settings in the real world, generally it is not a concern. This is because under this situation a more bottlenecked link (36/12 Kbps) exists between MS and BS. Therefore, using an infinite-bandwidth link to simulate the link between SGSN and GGSN does not affect GPRS simulation results.

Form Wireless Subnet

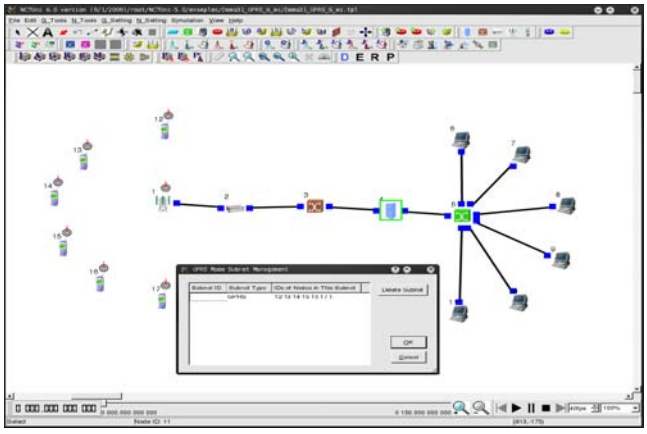
The icons of GPRS-related nodes are shown below: GGSN , SGSN , GPRS base station , GPRS phone , and GPRS pseudo switch . The following figure shows an example GPRS simulation case.

In NCTUns, the GPRS backbone network forms a single subnet regardless how many SGSNs, base stations, and phones are inside it. Using the following figure as an example, the devices on the left side of the GGSN form a single subnet. This is because in NCTUns, GPRS switches, SGSNs, and base stations are all treated as layer-2 devices while GGSNs are treated as layer-3 routers.

After inserting GPRS-related nodes, a user must use the "Form wireless subnet" ( ) tool to select all GPRS phones and all GPRS base stations to group them together to form a wireless subnet. Specifying this relationship enables the GUI program to automatically assign IP and MAC



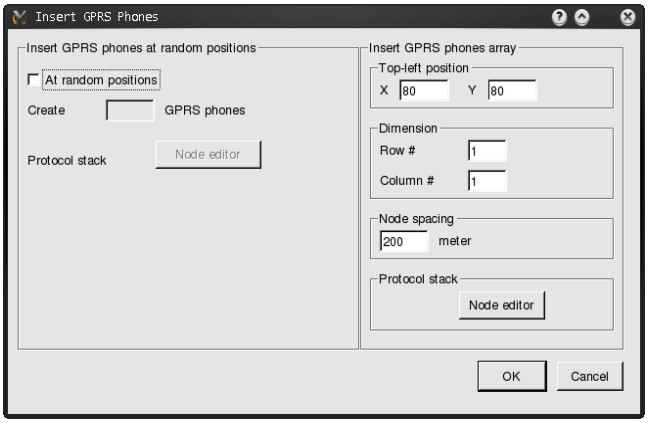
addresses to all GPRS phones, saving much time and effort of the user. The subnet ID of the GPRS subnet is automatically assigned by the GUI program and can be known by moving the mouse cursor over the blue interface box on the left side of the GGSN (see the above figure). The formed GPRS wireless subnets can be viewed and managed by executing the **Menu -> N_Tools -> GPRS Network -> Manage GPRS Subnets** command. The following figure shows the dialog box of this command.



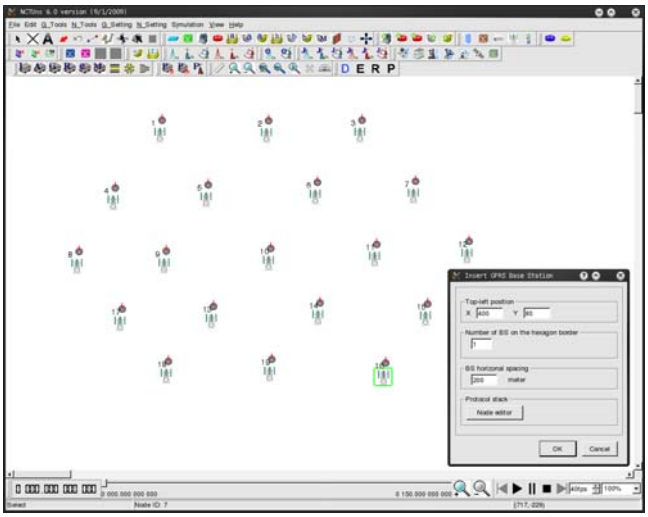
In NCTUns, the IP addresses assigned to GPRS phones can be viewed as “public” IP addresses in the simulated network. Any host on the simulated fixed network can send packets to a GPRS phone using the phone’s IP address as the destination IP addresses of these packets. Likewise, a GPRS phone can actively send its packets to any host on the simulated fixed network using the phone’s IP address as the source IP addresses of these packets.

Inserting Multiple Base Stations and Phones

If a user wants to create and insert multiple GPRS phones into the working area in just one step, the **Menu -> N_Tools -> GPRS Network -> GPRS Phone -> Insert GPRS Phones** command can be executed. The following figure shows the dialog box of this command.

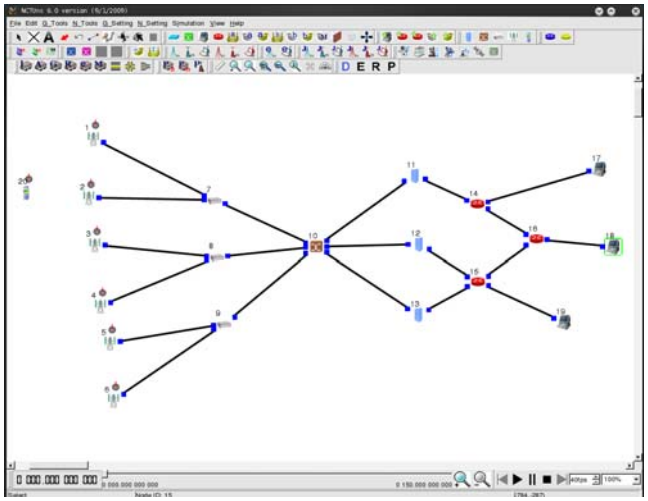


If a user wants to create and insert multiple GPRS base stations into the working area in one step, the **Menu -> N_Tools -> GPRS Network -> GPRS BS -> Insert GPRS Base Stations** command can be executed. This command will create multiple base stations and place them in a hexagon form. In the dialog box shown in the following figure, the user can specify the top-left position of the created base stations, the number of base stations on the hexagon border, and the horizontal spacing in meter between two neighboring base stations. This figure shows a hexagon that has three base stations placed on each of its borders.

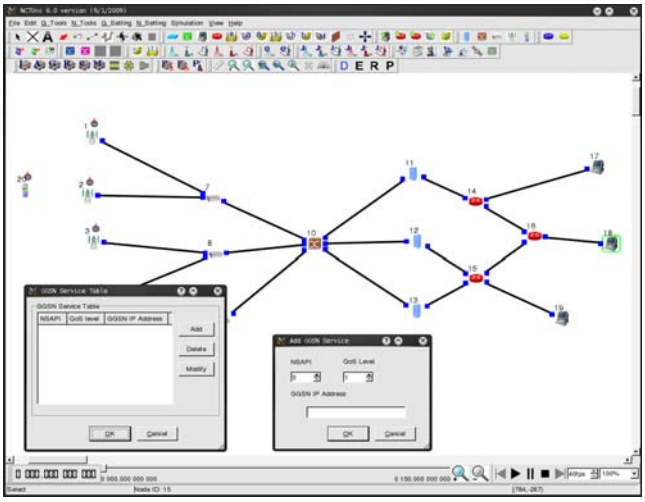


Choosing an Outgoing GGSN

A GPRS network can have multiple GGSNs connecting it to the fixed network. Outgoing phone traffic with different NSAPI (Network Service Access Point Identifier) and QoS level can be routed and directed to different GGSNs for receiving different QoS treatments. The following figure shows a GPRS network with three GGSNs.



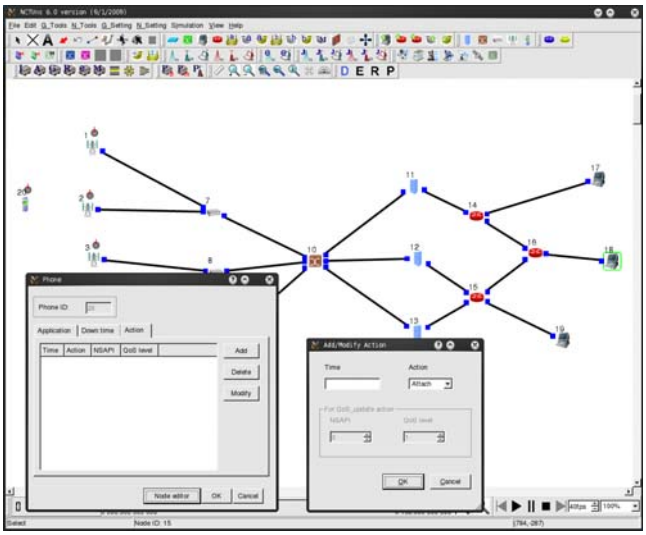
To specify the mapping between NSAPI, QoS level and the outgoing GGSN, the **Menu -> N_Tools -> GPRS Network -> GPRS GGSN -> Edit GPRS Service Table** command can be executed. The following figure shows its dialog box. Note that this mapping table is only meaningful for phone traffic going out from the GPRS network. For traffic that is originated from the fixed network and destined to one phone in the GPRS network, the user cannot control which GGSN will be chosen as the entry point into the GPRS network. Instead, the routing entries that determine which GGSN will be used are automatically generated by the GUI program.



Setting Phone and BS

Phone

Before using a GPRS phone, a user must first attach it to the GPRS network. This operation allows the GPRS network to know the existence of the phone. In addition, before sending traffic from a phone, via a SGSN and a GGSN, to a host in the fixed network, the user must first activate the phone so that a PDP (Packet Data Protocol) context is installed in the chosen SGSN and GGSN for routing. After the activation, the user may update the QoS level of the phone's traffic. When the data transfer is completed, the user can deactivate the phone, and then detach the phone from the GPRS network. These five commands are provided in the **[Action]** tab of the phone's dialog box. The following figure shows the dialog box of this command.

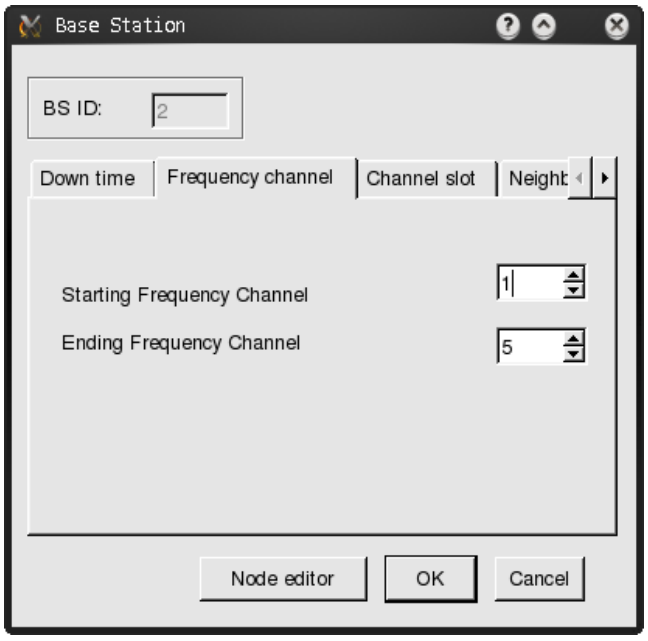


Because internally a phone functions like a host, any real-world application program can be run on a GPRS phone. As such, a user can specify an application command string something like the following: "stcp -p 8000 1.0.3.2" in the **[Application]** tab, where 1.0.3.2 may be the IP address of a host in the fixed network. Note that the start time of any specified application program must be later than the start time of the phone's "attach" action command. Otherwise, the packets of the launched application program will not be accepted by the GPRS network.

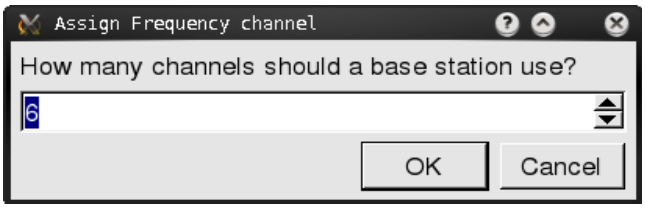
Base Station

In the **[Frequency Channel]** tab of the base station dialog box, a user can specify a range of frequency channels allocated to and used by this base station. This range is specified by the starting and ending channel numbers. In a

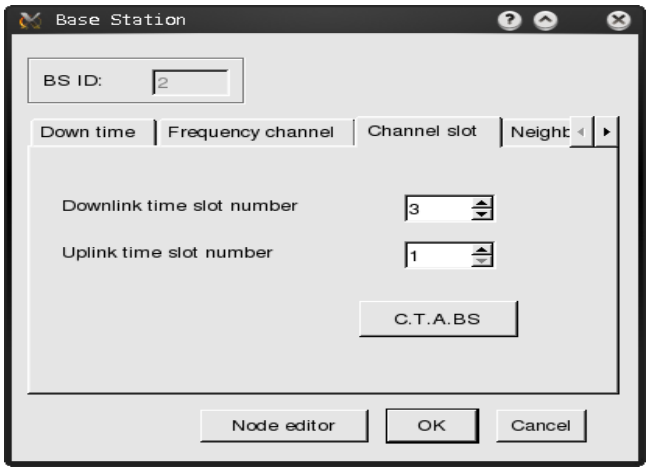
GPRS network, neighboring base stations use different frequency channels to avoid signal interference and packet collisions. Therefore, the user needs to be careful when assigning frequency channels to base stations.



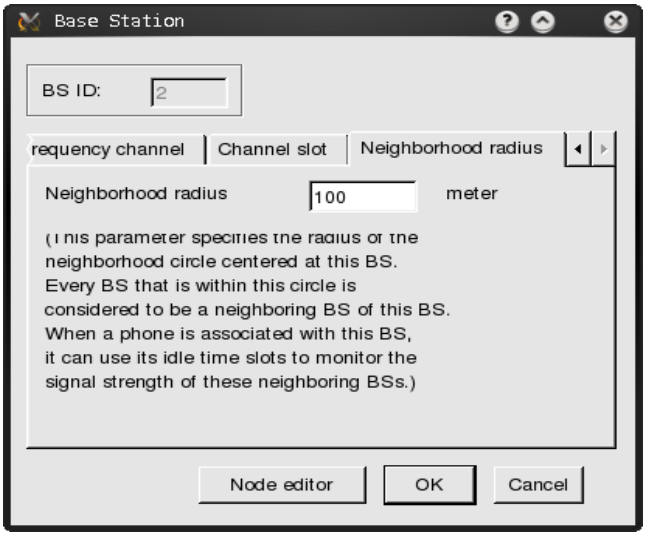
When there are many base stations in a GPRS network, opening the dialog box of each base station to configure its channels may be tedious. To do this task, a user can execute the **Menu -> N_Tools -> GPRS Network -> GPRS BS -> Assign Frequency Channel** command to specify how many channels a base station should use. This command will automatically give every base station the specified number of channels. Note that the channels that are automatically assigned by the GUI are totally different. Thus, no base station will be given a channel that is already given to another base station. In the real world, channel re-using is commonly performed to save the number of required channels for a GPRS network. However, during this automatic channel assignment process, no channel re-using is attempted because the GUI lacks the required intelligence to perform this task.



In the **[Channel Slot]** tab of the base station dialog box, a user can specify how many time slots are allocated to the downlink and uplink traffic for a GPRS user. The default values are 3 and 1 for the downlink and uplink traffic, respectively. To let all other base stations use the same time slot numbers, the user can click the “C.T.A.B.S” button to copy the settings to all base stations.



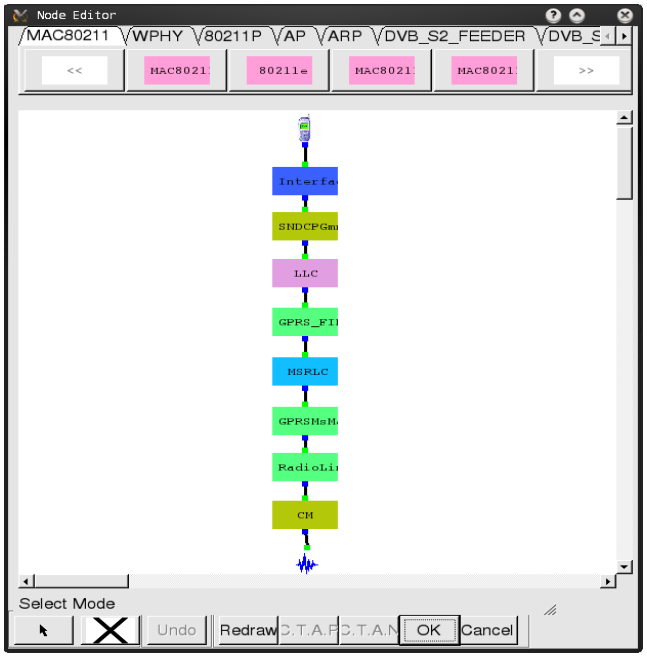
In the **[Neighborhood Radius]** tab of the base station dialog box, a user can specify the radius of the neighborhood circle centered at this base station. Every base station within this circle is considered to be a neighboring base station of this base station. When a GPRS phone is associated with this base station, this base station will notify it of the existence of these neighboring base stations. The GPRS phone then uses its idle time slots to monitor the signal strength of these neighboring base stations. This design will facilitate roaming and handoff between neighboring base stations. The default value is 100 meters. A user can change this value to suit his (her) needs.



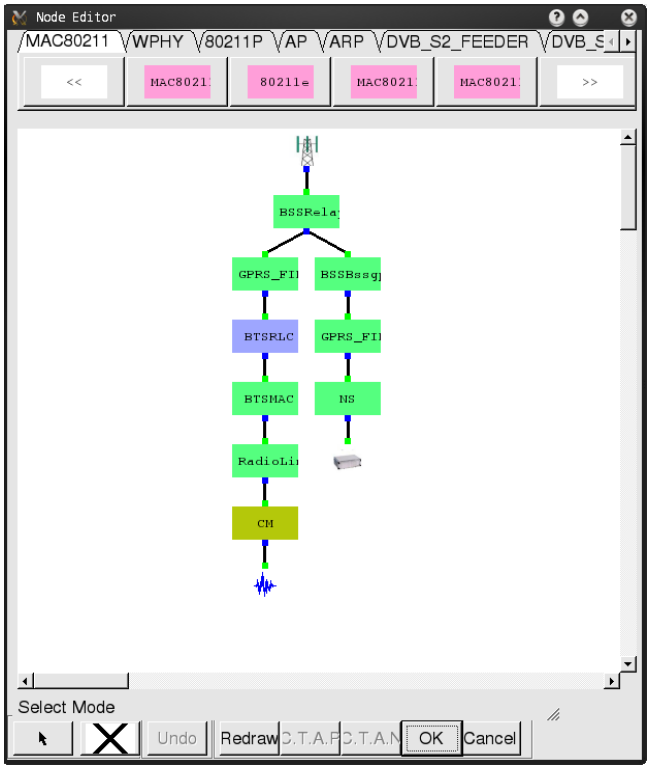
Protocol Stack

In the following, the protocol stacks used by GPRS devices are shown.

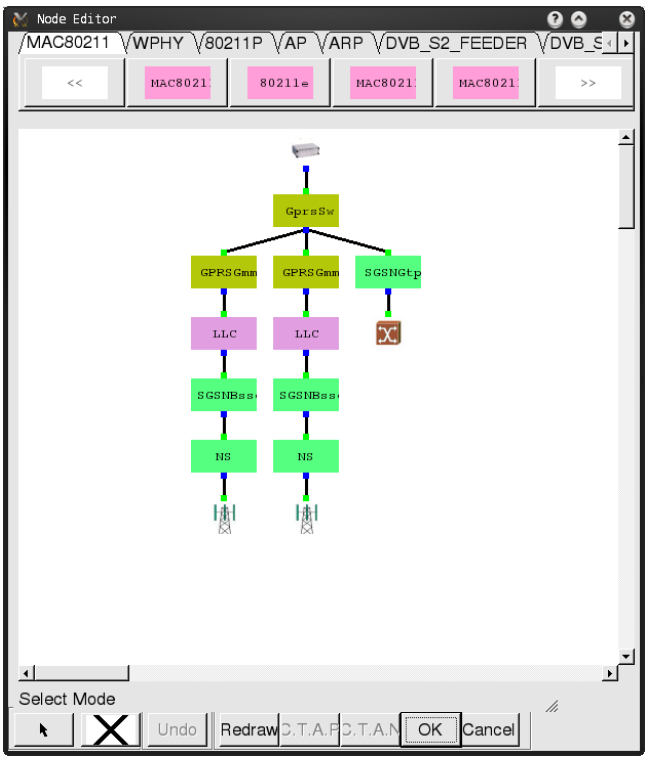
Phone



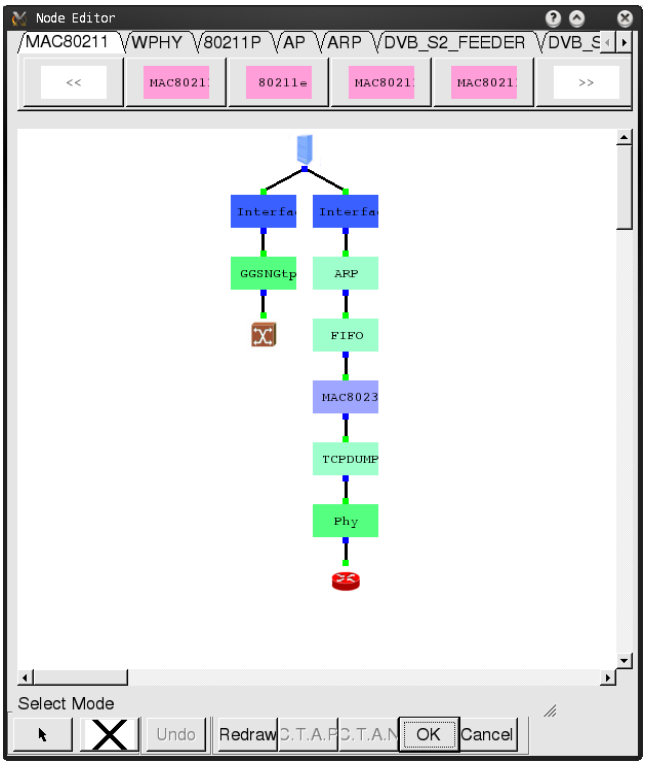
Base Station



SGSN



GGSN

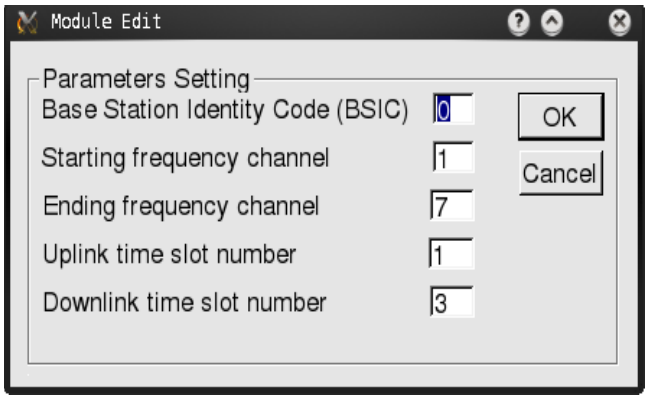


Protocol Modules

In the following, the parameters of some protocol modules are shown and explained.

BTSMAC

The parameters provided in the BTSMAC module deal with channel and time slot usages. The values of these parameters shown in the module dialog box reflect the values set in the **[Frequency Channel]** and **[Channel Slot]** tabs of the dialog box of the base station. The Base Station Identity Code (BSIC) is assigned by the GUI automatically. Each of the base stations that connect to a single SGSN is assigned a different number ranging from 0 to 7. The maximum number of base stations that can connect to a SGSN is 8. The following figure shows the dialog box of the BTSMAC module.



Summary

This chapter presents how to use NCTUns to conduct GPRS simulations. A GPRS network is a complicated network with various protocols. It is out of the scope of this chapter to explain the details of GPRS. Readers should reference some GPRS textbooks to understand the meanings of various GPRS parameters.

Reference

[1] Y.B. Lin and I. Chlamtac, “Wireless and Mobile Network Architectures,” John Wiley and Sons, 2001.

[2] R.J. “Bud” Bates, “GPRS: General Packet Radio Service,” McGraw-Hill, 2002.

13. DiffServ QoS Networks

Quality of service (QoS) is desired for users who request a better network service than the "best effort" service offered by the current Internet. Differentiated service (DiffServ) is one kind of QoS mechanism proposed to provide differentiated services among different users. This chapter illustrates how to use NCTUns to conduct DiffServ simulations.

DiffServ Concept

Quality of service on networks can be provided by strictly guaranteeing a traffic stream's end-to-end performances such as bandwidth, delay, delay jitter, packet loss rate, etc. or by differentiating traffic classes and giving them different QoS treatments. The first approach (IntServ) may provide a better service than the second one (DiffServ). However, the cost for offering the first service is much higher than the cost for offering the second service.

In DiffServ, a simple and coarse method is used to provide differentiated classes of service for Internet traffic. The DiffServ approach uses a small, well-defined set of building blocks from which various aggregate behaviors can be built. A small bit pattern in each packet, which is in the IPv4 TOS field, is used to mark a packet to receive a particular forwarding treatment, or per-hop behavior (PHB), at each network node.

In a DiffServ (DS) domain, two different types of routers exist. They are called the boundary router and interior router, respectively. On a boundary router, traffic incoming into the DS domain needs to be classified and conditioned. Traffic classification is carried out by a classifier which classifies traffic into different classes based on the traffic profile or the service contract. For example, one can use the (source IP address, destination IP address, source port number, destination port number, protocol) five-tuple to specify a traffic flow and classify its packets into a traffic class. Traffic conditioning is carried out by a conditioner, which may consist of a meter, marker, shaper, and dropper. The function of a traffic conditioner is to meter a traffic flow to see if it exceeds its traffic profile, mark the packets whose usage exceeds the traffic profile as low-priority packets, delay the transmission of these packets, or even drop these packets. Normally, the token bucket scheme is used to specify a traffic profile.

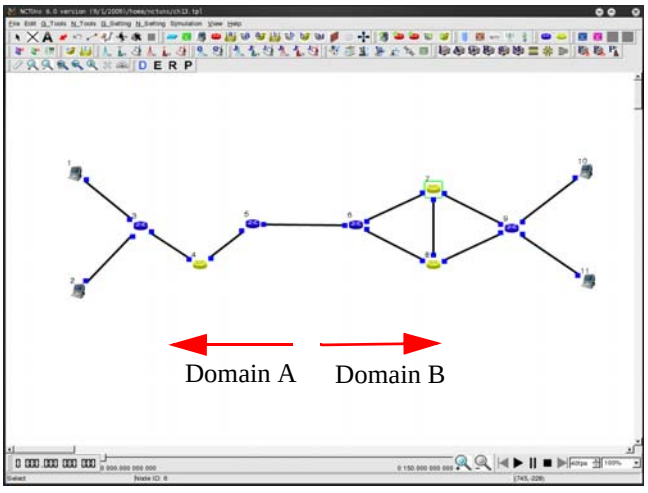
On an interior router, incoming packets are dispatched to different traffic-class queues for receiving different QoS treatments. Dispatching a packet is based on the DiffServ codepoint (bit-pattern) marked on its TOS field, which is marked when the packet passes through a Diffserv boundary router.

Several forwarding treatments, or called PHB, are defined and provided for a Diffserv network. They are, "best effort" (BE), "Expedited Forwarding" (EF), and "Assured Forwarding" (AF). The service provided by BE PHB is equivalent to the "best effort" service provided by the current Internet. The service provided by EF PHB can be described as premium service by which the packets of a traffic flow will experience very tiny delays and no packet loss. The services provided by AF PHB is to forward the packets of a traffic flow with high assurances. This service is better than the BE service but worse than the EF service.

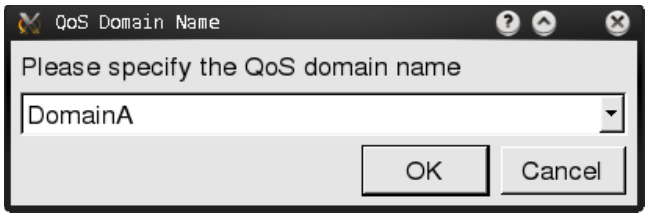
DiffServ is composed of several schemes and protocols. This chapter only provides a brief overview of DiffServ. For more detailed information about DiffServ, readers should reference [1, 2, 3, 4].

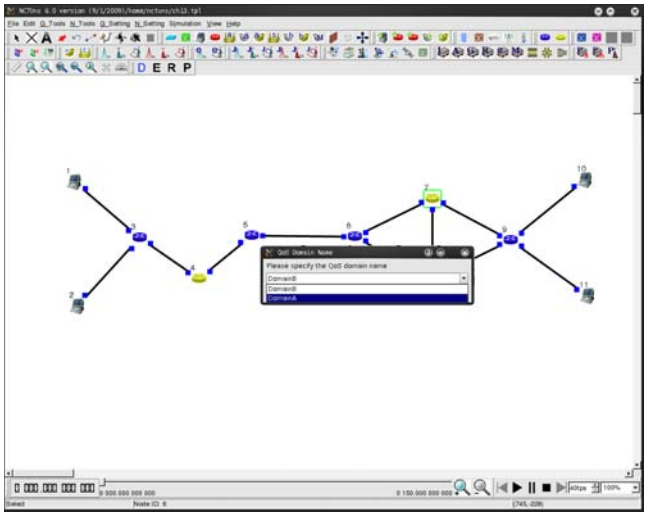
DiffServ Network Creation

In the following figure, two DS domains exist. One is on the left while another is on the right.

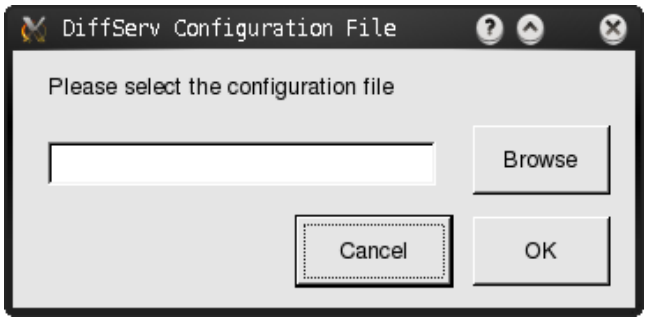


When a user inserts a boundary router or an interior router into the working area, the GUI will pop up a dialog box asking the user to specify the name of the DS domain that this router belongs to. A user needs to input a DS domain name at this time. If the DS domain name for this new router is the same as a name that has been specified before, the user can select it from the DS domain name menu provided in this dialog box to avoid typing. The following two figures show these operations.





The DiffServ boundary and interior routers that belong to the same DS domain will use the same set of traffic classifier, conditioner, and PHB for the packets passing through them. Multiple DS domains can exist in a simulated network. The rules and parameters for the DS domains existing in a simulated network should be specified in a configuration file and read by the GUI and the simulation engine. This configuration file is a text file and can be edited by any editor such as vi or emacs. A user can execute the **Menu -> N_Tools -> QoS DiffServ Network -> Select Configuration File** command to select it. This file will be copied into the .sim directory of this simulation case and renamed to dsdmdf.txt. The DiffServ-related protocol modules will read the dsdmdf.txt file during simulation. The following figure shows the dialog box of this command.



DiffServ Domain Configuration File Format

Fifteen codepoints are provided in NCTUns. They are for BE (best effort), EF (expedited forwarding), NC (network control), and 12 AF (Assured Forwarding) services. Assured Forwarding (AF) PHB group provides forwarding of IP packets in 4 independent AF classes. Within each AF class, an IP packet can be assigned one of 3 different levels of drop precedence. An IP packet that belongs to an AF class i and has drop precedence j is marked with the AF codepoint AF_{ij}.

These PHB services and their corresponding codepoints are listed as follows.

[PHB service]	*[Codepoint]*
AF1	*001010 001100 001110 (AF11 AF12 AF13)*
AF2	*010010 010100 010110 (AF21 AF22 AF23)*
AF3	*011010 011100 011110 (AF31 AF32 AF33)*
AF4	*100010 100100 100110 (AF41 AF42 AF43)*
EF	*101110*
NC	*111000 110000 101000 100000*
BE	*000000*

In the DS domain configuration file, multiple DS domains can be defined. The definitions of each one are specified in the following format.

DefineDSDomain

Name *Enter_A_DS_Domain_Name_Here*

RuleAdd *[sip] [dip] [sport] [dport] [proto] [PHB] [rate:Mbps] [size:Mb] [maxqlen]*

RuleAdd ..

QueAdd *[type] [name] [weight] [maxqlen] [ts1] [ts2] [MDR]*

QueAdd ...

EndDomainDefine

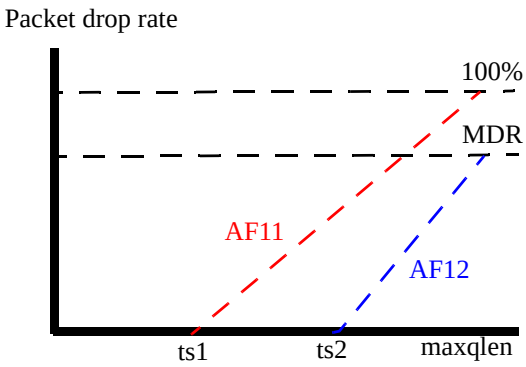
In the above format, **bold** words are keywords and *italic* words represent the words that should be replaced by the user with appropriate settings. Multiple RuleAdd and QueAdd lines can exist in a DS domain definition. RuleAdd lines are for the traffic classifier and conditioner located in boundary routers while QueAdd lines are for the packet schedulers located in interior routers. RuleAdd uses the common five-tuple (source IP address, destination IP address, source port number, destination port number, protocol) to specify a traffic flow. The "protocol" field can be TCP (6) or UDP (17). Any of these fields can be entered the "*" wild card, which means "don't care." The packets of the specified traffic flow are classified to receive the specified PHB service, which can be one of BE, NC, EF, AF11, AF12, AF13, AF21, AF22, AF23, AF31, AF32, AF33, AF41, AF42, and AF43.

The meter used to measure the usage of a traffic flow is a token bucket. Its token rate is *rate* Mbps and its bucket size is *size* Mbits. When a packet arrives at the token bucket but cannot find a token, it cannot be sent out and needs to wait in a queue waiting for the required token. The maximum queue length allowed for this queue is set to be *maxqlen* packets. When a packet arrives but finds that this queue is already full, it is handled according to the following rules. First, if it is an EF packet, it will be dropped. Second, if it is an AF11 packet, it will be downgraded to an AF12 packet and enqueued. Third, if it is an AF12 packet, it will be downgraded to a BE packet and enqueued. Lastly, if it is a BE packet, it will be dropped if the current queue length is greater than *2 * maxqlen*, otherwise it remains a BE packet and is enqueued.

QueAdd specifies how much bandwidth and memory buffer resources of an interface should be allocated to a PHB service. The *type* field specifies the PHB service. The *name* field specifies the name of this service, which is not important and can be the same as the type. (For example, it can be specified as gold, silver, or bronze.) The *weight* field affects the amount of bandwidth that is allocated to this PHB. The actual amount is a fraction of the interface bandwidth. This fraction is the ratio of *weight* to the sum of all *weights* specified in all QueAdd lines. For example, suppose that there are four QueAdd lines and the weights of these queues are 1, 2, 3, and 4, respectively. Then, queue 1 will be allocated 1/(1+2+3+4) = 1/10 of the interface bandwidth.

The *maxqlen* field specifies the maximum queue length allowed for the queue used to buffer packets marked with this PHB's codepoint. The *ts1*, *ts2*, and *MDR* fields are meaningful only for AF traffic. The *ts1* and *ts2* specify the low threshold and high threshold of the queue length. They are used to provide different packet dropping probabilities for different dropping precedences inside an AF class. The current queue length is compared against these two thresholds to determine the packet dropping rate for incoming packets.

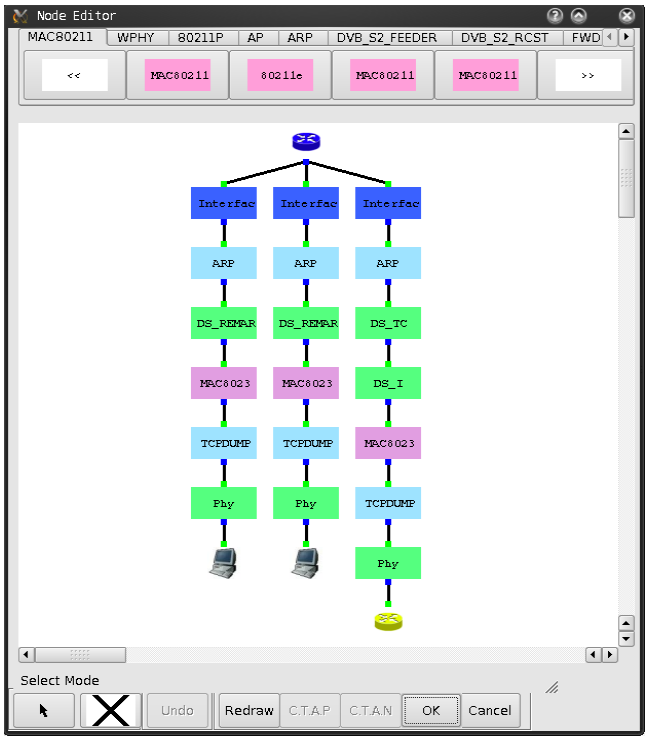
Using the AF1 class as an example, when the current queue length is greater than *ts1*, AF11 packets will start to be dropped. However, only when the current queue length is greater than *ts2*, will AF12 packets start to be dropped. The *MDR* field specifies the maximum packet drop rate for AF12 packets. Its default value is 80%. The relationship between these parameters is illustrated in the following figure.



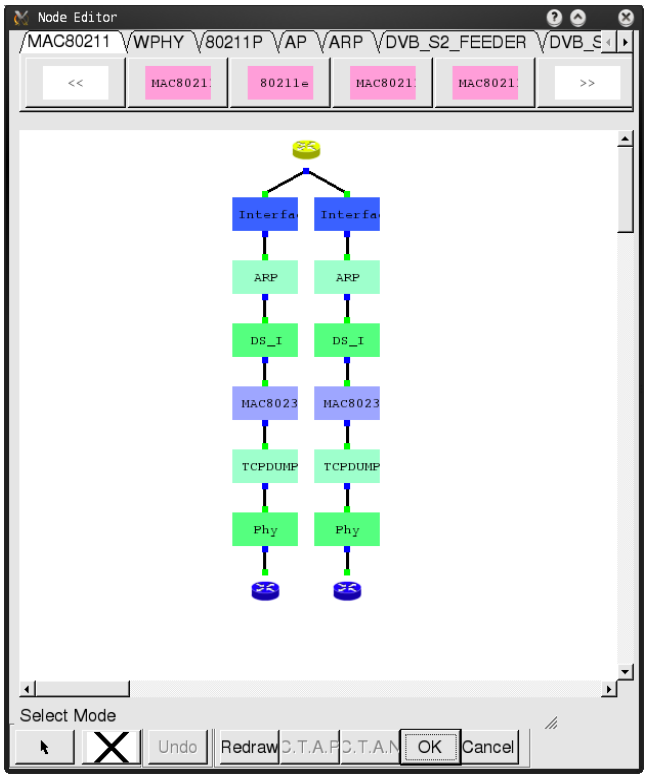
DiffServ Protocol Stack

In the following figure, the protocol stack of the DiffServ boundary router is shown. In the protocol stack of the interface that connects the boundary router to an interior router a DS_TC and a DS_I protocol modules are used. The former module deals with traffic classification and conditioning while the latter module deals with packet scheduling.

In the following figure, the protocol stack of the DiffServ interior router is shown. In the protocol stack of each interface, a DS_I protocol module is used. This module is the same as the DS_I module used in a boundary router. Its task is to schedule the transmissions of packets based on their codepoints.

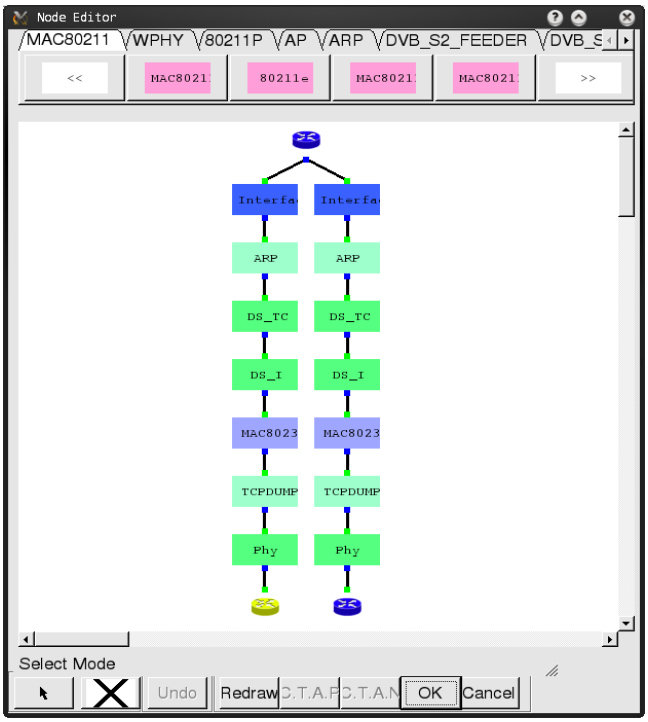


The protocol stack of a DiffServ boundary router.



The protocol stack of a DiffServ interior router.

If a boundary router connects to another boundary router that belongs to a different DS domain, in the protocol stack of the interface that connects this boundary router to that boundary router, a DS_REMARK protocol module is used. This module clears the DS codepoints carried in the packets that leave the current DS domain so that the boundary router in the next DS domain can correctly mark them. The following figure shows this type of protocol stack.



DiffServ Protocol Module

A user need not set any parameter in the dialog boxes of the DS_TC, DS_I, and DS_REMARK protocol modules. The required parameter values should be specified in the DiffServ configuration file described before.

Summary

This chapter presents how to use NCTUns to conduct QoS DiffServ simulations. A DiffServ network can provide differentiated quality of services to different traffic classes. Such a network is composed of boundary and interior routers. A boundary router is responsible for classifying and conditioning traffic while an interior router is responsible for scheduling packets. It is out of the scope of this chapter to explain the details of DiffServ. Readers should reference some textbooks to understand the meanings of various DiffServ parameters.

Reference

[1]RFC 2475, “An Architecture for Differentiated Services.”

[2] RFC 3246, “An Expedited Forwarding PHB.”

[3] RFC 2597, “Assured Forwarding PHB Group.”

[4] RFC 3140, “Per Hop Behavior Identification Codes.”

14. Optical Networks

Optical networks are commonly used in the backbone of the Internet to provide long-distance and large-bandwidth links. This chapter illustrates how to use NCTUns to conduct simulations of optical networks, which include traditional circuit-switching optical networks and more advanced optical-burst-switching (OBS) networks.

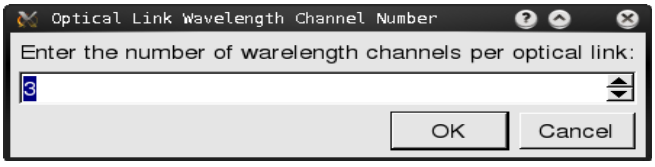
Optical Network Concept

An optical network is composed of optical links, optical switches, and optical edge routers. Optical edge routers are located at the boundary of an optical network. They inter-connect an optical network with a non-optical network such as a fixed Ethernet network. An optical edge router is created by using the same tool button used for creating a normal router in a non-optical network. This is because once a newly-created router is connected to an optical switch, the GUI program knows that this router is an optical edge router. As such, the GUI program installs relevant optical modules into the protocol stack of the interface that connects to the optical switch.

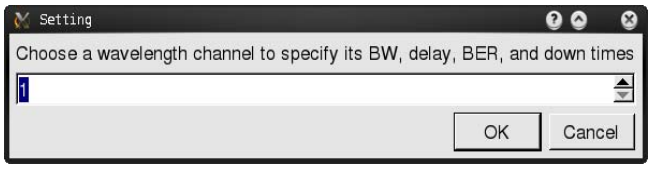
Similarly, an optical link is created by using the same tool button used for creating an Ethernet link between two non-optical devices. This is because once a link is created between two optical switches or between an optical switch and an optical edge router, the GUI program knows that this newly-created link should be an optical link.

Inside an optical network, only optical switches can be used to form the optical network and no other types of devices are allowed. Two types of optical switches are currently supported in NCTUns. The first one is called “optical circuit switch” while the second one is called “optical burst switch” . They cannot be mixed to form an optical network. Instead, an optical network can be formed by only one type of optical switches.

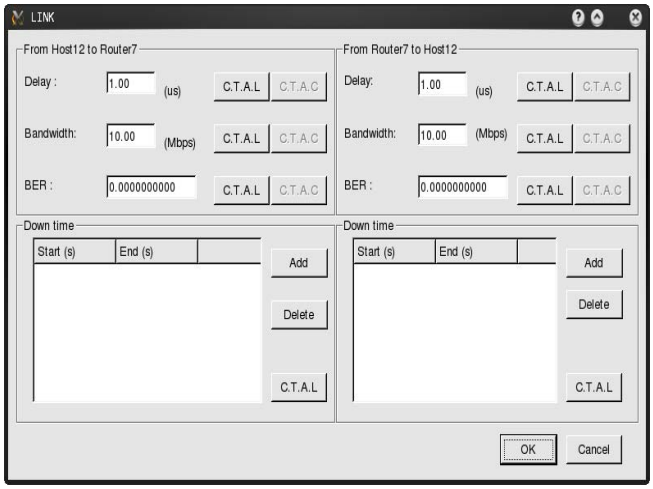
Using the Wavelength Division Multiplexing (WDM) technique, an optical link is divided into several channels each operating at a different frequency (or said to use a different wavelength). In NCTUns, when the first optical switch is added to the topology editor, the GUI program will pop up a dialog box asking the user how many channels an optical link has (see the following figure). In a NCTUns simulation case, all optical links must have the same number of channels. This parameter can also be set by executing the **Menu -> N_Setting -> Optical Network -> Set Optical Link Wavelength Channel Number** command**.** Once the first optical switch is added to the topology editor, a user can no longer change the value of this parameter.



The wavelength channels of an optical link are independent and can be individually configured. A user can set the bandwidth, signal propagation delay, bit-error-rate, and down time periods of a specific channel of an optical link. When a user double-clicks an optical link, a dialog box will pop up asking the user which channel to specify. The following figure shows this dialog box.

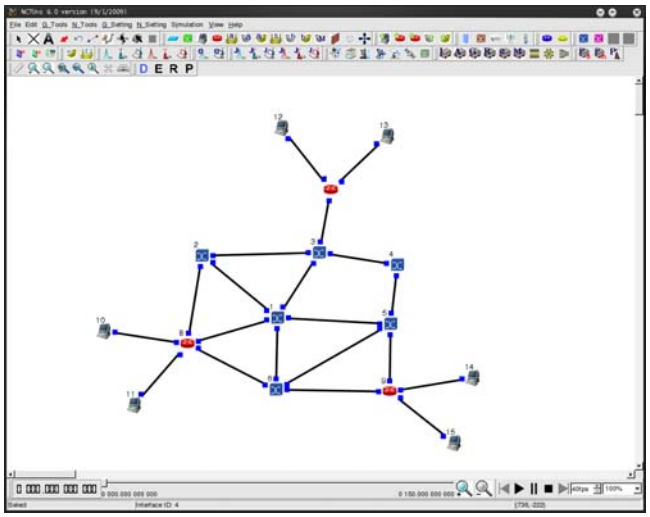


After entering the channel ID, a dialog box for this specified channel will show up (shown in the following figure). In the figure, when a user clicks a parameter field’s **C.T.A.C** button, the field’s current value will be copied to all channels of the same optical link. On the other hand, when a user clicks a parameter field’s **C.T.A.L** button, the field’s current value will be copied to all channels of all optical links in the network.



Circuit Switching Optical Network

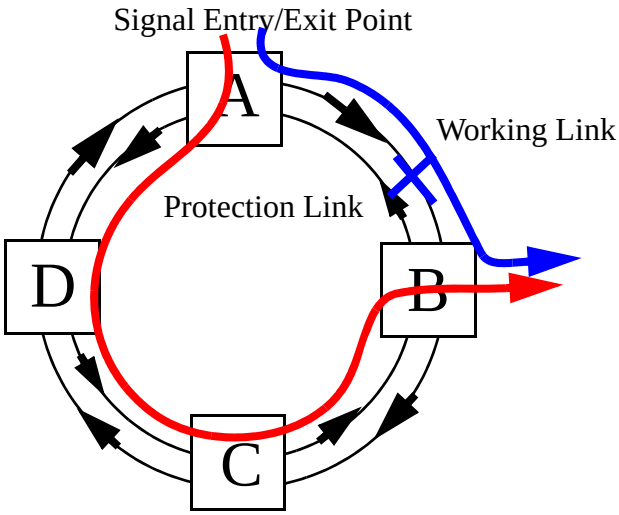
When an optical network is formed by optical circuit switches, we call this type of network a “circuit-switching optical network.” The following figure shows a network that is composed of a circuit-switching optical network and a fixed Ethernet network.



An example circuit-switching optical network.

To protect a circuit-switching optical network and enable it to recover from link or node outages, various protection schemes can be used. For example, 1+1 unidirectional point-to-point link, 1+1 bidirectional point-to-point link, 1:N one protection link shared by N working links, 2 fiber bidirectional line switched ring (2F-BLSR), 4 fiber bidirectional line switched ring (4F-BLSR), etc. NCTUns uses 2F-BLSR to protect a circuit-switching optical network.

In such a scheme, a bidirectional ring is used to connect all optical switches. The links on one unidirectional ring carries traffic and are called “working links” while the links on the other unidirectional ring serve as backup links and are called “protection links.” If a working link breaks between two optical switches (says the link from switch A to switch B), the source switch of the broken link (A) will divert its traffic to a link on the protection ring. The traffic will then travel on the protection ring and eventually arrives at the intended switch (B). The protection operation is automatically done at layer 2 and is transparent to upper layers. Therefore, traffic flowing at the IP layer (e.g., a TCP connection downloading a web page) can continue its journey to its destination switch without disruptions. The following figure shows how a 2F-BLSR protection scheme works.



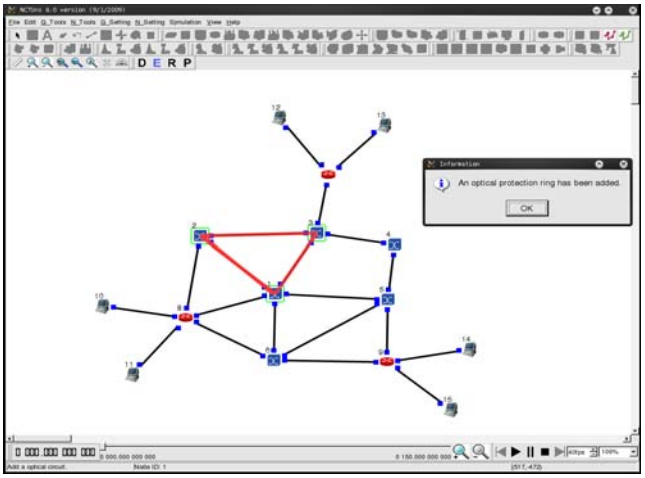
The 2 fiber bi-directional line switched ring protection scheme.

On a circuit-switching optical network, a user can specify several 2F-BLSRs to protect the network. If protection is not needed, a user need not specify any 2F-BLSR. To specify a 2F-BLSR, a user can use the “optical protection ring” tool button  to sequentially select the switches that should be on the ring. The sequence of the switches selected is important as it defines the direction (clockwise or counter-clockwise) of the working ring of the 2F-BLSR.

The operation used to select switches on the ring is like the operation for specifying the moving path of a mobile node. A user first selects an optical switch by clicking on it. Then he (she) moves the mouse cursor to another optical switch and clicks it to select it as the next optical switch on the ring. The selected switch must be directly connected to the previous switch by an optical link. Otherwise, the protection scheme will not work properly. If the user changes his (her) mind and wants to cancel this ring, he (she) can right-click the mouse at any place to discard the current ring.

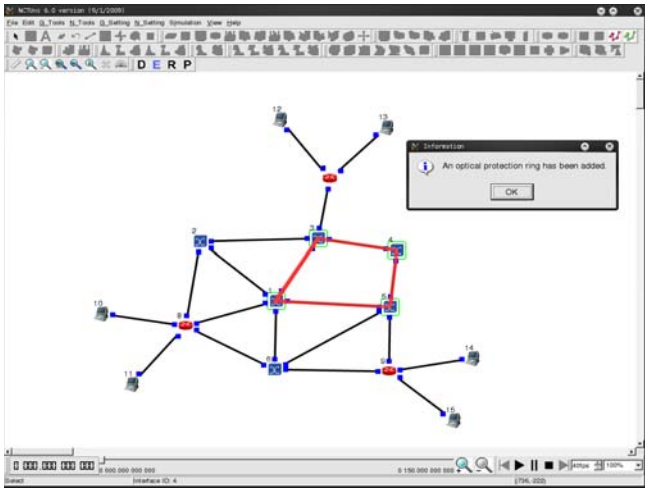
During the ring creation process, a thick red line is shown on the screen to indicate the current ring. A user needs to sequentially click all switches that should be on the ring. Finally, the user must click the first switch to close the ring. At this time, the specified ring is formed and added to the GUI program. The following figure shows that a 2F-BLSR protection ring has been configured and added to the GUI program.

Multiple protection rings may be configured on an optical network. If they do not overlap, there is no problem. However, if they overlap, care must be taken to ensure that the directions of their working rings are the same -- either

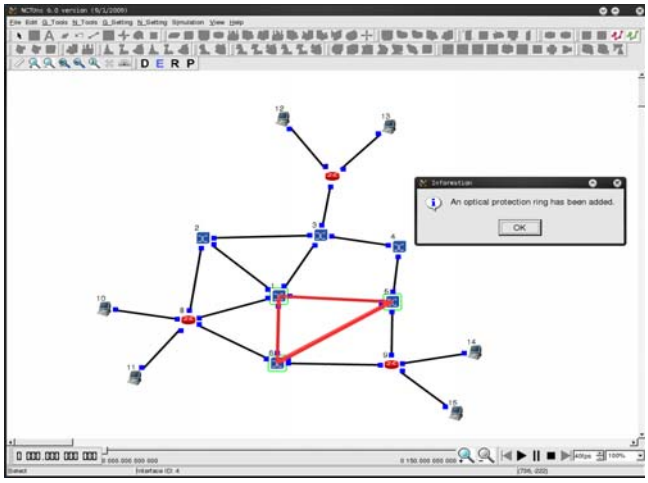


A 2F-BLSR protection ring has been configured for the circuit-switching optical network.

clockwise or counter-clockwise. The following figures show that the second and third 2F-BLSR protecting rings are added to the same network to protect all optical links. These three rings must have the same direction -- either clockwise or counter-clockwise. The reason for this restriction is that there can only be one working ring for each direction of an optical link. Following this restriction rule can ensure that this property is hold. For example, the optical link between 4th switch and 8th switch is on both the first ring and the second ring. If both rings are clockwise or counter-clockwise, there is exactly one working ring for each direction of the optical link.



The second 2F-BLSR protection ring has been configured for the circuit-switching optical network.



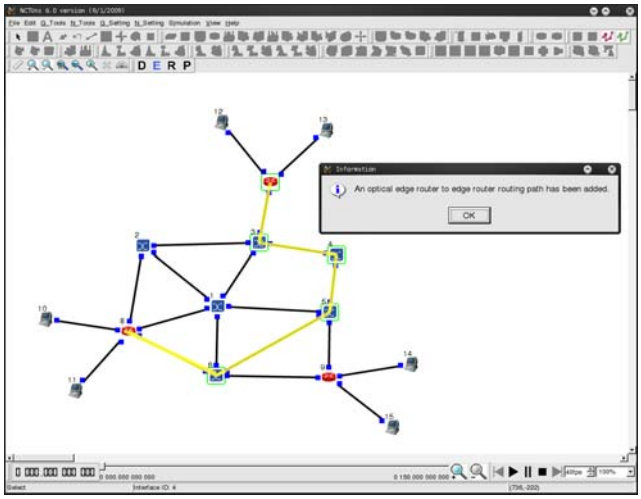
The third 2F-BLSR protection ring has been configured for the circuit-switching optical network.

After setting up protection rings, the next step is to set up light paths for every pair of optical edge routers in the optical network. In a circuit-switching network, before an optical edge router can forward any traffic through the optical network to another edge router, a light path must have been configured and set up between them. All traffic that is forwarded from an optical edge router to another optical edge router should travel over this configured light path. Usually, the lifetime of such light paths are long. After a light path is set up, it usually lasts for a few hours or a few days before being tore down due to link/switch failures or for load-balancing purposes.

In NCTUns, two methods are provided for setting up a light path. In the first method, a user can use the “optical edge router to edge router routing path” tool button to manually specify a routing (light) path between two optical edge routers. The operation used to specify a light path is similar to that used to specify a protection ring. The only difference is that a light path must start and end at two different optical edge routers while a protection ring must start and end at the same optical switch. During the light path creation process, a user can cancel the path by right-clicking the mouse at any place. A thick yellow line will be shown on the screen to indicate the current light path. The following figure shows that a light path between two optical edge routers has been created.

The sequence of the selected switches determines the light path and it is very important. If the light path needs to traverse over some protection rings, it should follow the directions of these rings so that its traffic can be transported naturally on the working rings of these rings. That is, if a protection ring is clockwise, the light path should also be

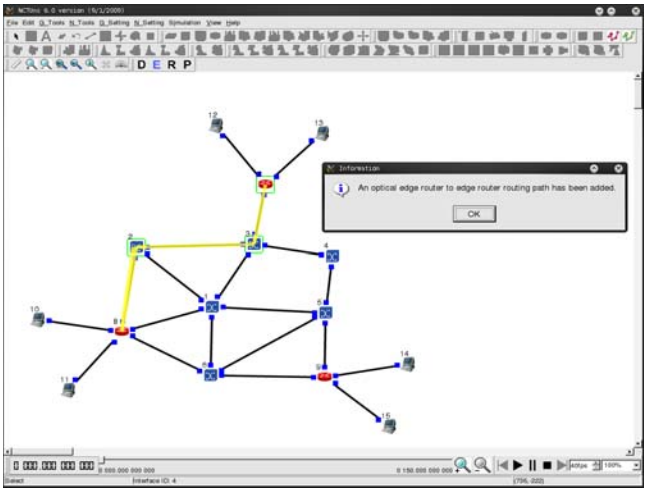
clockwise on the ring. This arrangement is the most efficient arrangement. The following figure shows the correct arrangement of the light path assuming that the underlying protection rings are clockwise.



A light path that follows the directions of its underlying protection rings.

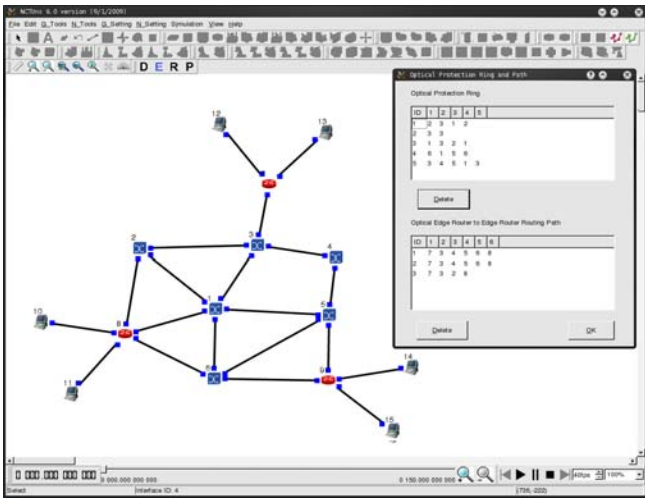
In contrast, if the user specifies a light path in such a way that it runs in the different direction than its underlying protection rings, although this light path can still work properly, this arrangement is the most inefficient arrangement in that the light path's traffic needs to traverse the whole working ring to reach its next switch. In the following figure, although the light path is shorter than the light path in the previous figure and it seems that the light path's bandwidth usage is more efficient, in fact this is not the case. On the first ring (its direction is clockwise), in order to send traffic from 5th switch to 1st switch (counter-clockwise), 5th switch needs to forward the traffic through 7th, 6th, 8th, 4th switches on the clockwise working ring to let the traffic reach 1st switch. The same problem also occurs on the third ring and the situation is even worse because to send traffic across a counter-clockwise link, the traffic needs to traverse the whole working ring and this penalty occurs twice on the third ring.

The second method to create a light path is to create it dynamically. In this method, when a packet needs to be forwarded from an optical edge router to another optical edge router and the light path between them has not been set up, the optical modules in NCTUns simulation engine will find and set up a light path for them automatically. Therefore, if light paths are not the focus of the simulation, a user need not manually configure the light paths between every pair of optical edge routers.



A light path whose direction is against the directions of its underlying protection rings.

After a user has created several protection rings and light paths, he (she) may want to delete some of them or see how they traverse on the optical network. To do this operation, a user can execute the **Menu -> N_Tools -> Optical network -> Manage Optical Network Protection Rings and Edge Router to Edge Router Routing Paths** command. The following figure shows the dialog box of this command. In this dialog box, to delete a protection ring or a light path, a user needs to select it first. This operation can be done by clicking the ID of the ring or the light path.

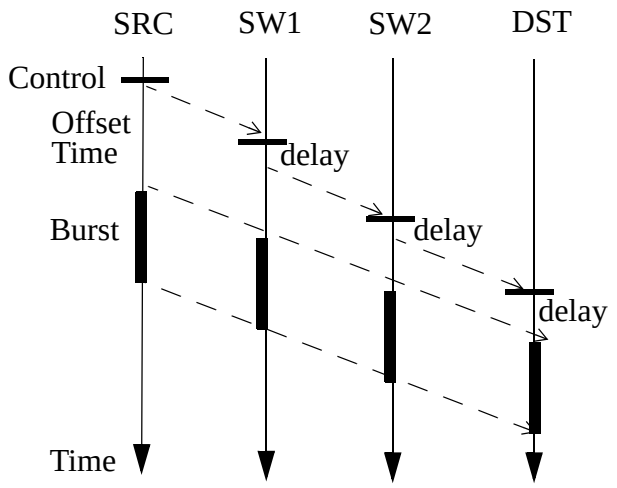


Configured protection rings and light paths can be managed in this dialog box.

After these settings, the user can specify the application programs to be run up on hosts (e.g., stcp and rtcp) and start executing the simulation.

Optical Burst Switching (OBS) Network

Optical burst switching (OBS) [1, 2] is a method for transporting traffic over a bufferless optical WDM network. At a source node, packets are grouped into a burst and sent together as a unit before they are switched through the network all optically. Before sending a burst, the source node first sends a control packet along the burst's routing path to configure every switch on the path. The control packet is sent over an out-of-band channel. It will be electronically processed at each switch so that the switch can allocate resources (e.g., schedule transmission time slots.) for its burst in real time. The time offset between sending the control packet and its burst should be large enough. This is to ensure that the control packet can always arrive before the corresponding burst at each intermediate switch. The following figure shows the mechanism of the OBS network.



The source node separates the transmissions of the control packet and the burst by an offset time. Because the control packet needs to be electronically processed at each intermediate switch, it will be slightly delayed compared to the burst transmission in the optical domain.

The control packet contains information about routing, the burst length, and the offset time. The routing information is for the switch to decide the outgoing interface for the burst. The length information tells the switch how much time the burst transmission will last. The offset time information lets the switch know that a burst will arrive after a time interval given by the offset time. With these information, the optical switch will try to reserve the specified period of time at the chosen outgoing interface for the burst. If that period of time has not been allocated to any other burst, the optical switch can successfully make the reservation. Otherwise, the switch simply discards the control packet without returning any feedback to the source node. At each intermediate switch, when the control packet arrives, the optical switch performs the same procedure to reserve resource for the control packet's burst. This operation repeats until the control packet successfully reaches its destination node or is discarded at some switch.

In OBS, burst priority and QoS can be supported in various ways. For example, a newly-arriving high-priority burst may be allowed to preempt a low-priority burst that already made a successful reservation. In [3], the authors proposed using different offset times for different burst priorities. The offset time for a high-priority burst is set to be longer than that for a low-priority burst. With such a setting, because the control packets associated with high priority bursts can reserve their required resource at an earlier time, they will have a higher chance to successfully reserve their required resource. In contrast, the control packets associated with low-priority bursts will less likely make successful reservations. As such, they and their corresponding bursts will experience a higher drop rate.

This control-packet signaling protocol is purposely designed to be one-way rather than two-way. That is, the source node need not wait for the reply of the source-to-destination reservation request to come back before sending its burst. If instead a two-way signaling protocol is used, in optical networks with high link bandwidth and large RTTs, tremendous optical bandwidth would be wasted during the RTT, because no packets can be sent during this period of time. In contrast, using the proposed one-way signaling protocol, this period of waiting time can be reduced to a fixed and tiny value, which is the used time offset.

In today's WDM networks, circuit (wavelength) switching, optical packet switching, and optical burst switching are the three main competing technologies. Potentially, the optical packet switching technology can provide the highest link utilization among the three technologies. However, it is not mature yet. The circuit (wavelength) switching technology is practical and being used. However, its link utilization is low. The optical burst switching technology can be thought of as a compromise design between the optical packet switching and the circuit (wavelength) switching technologies. By allocating a link's wavelength (light channel) only for the duration of a burst and statistically sharing the link among bursts belonging to different traffic flows, it provides a better link utilization than the (static) circuit switching technology.

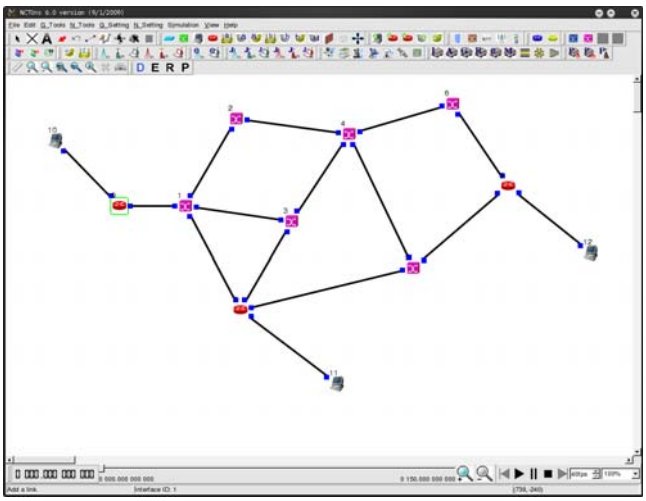
Although the OBS technology provides a higher link utilization than circuit (wavelength) switching technology, its performance is not satisfactory. Due to the optical switch's bufferless property, when multiple bursts contend for the same link at about the same time, only one burst can be successfully switched in the optical domain, and all other overlapping bursts need to be dropped. This results in low link utilizations and high burst loss rates.

Some existing contention resolution schemes for photonics packet networks such as fiber-delay lines (FDLs) and deflection routing may be used in optical burst switching networks. However, these methods have their own drawbacks. For FDLs, they are costly and their buffering capability is limited. For deflection routing, packets may be transported out-of-order and thus lowering a TCP connection's achievable throughput. Another method is to use multiple wavelength channels and convert a burst's wavelength to another wavelength when there is a burst collision. However, optical wavelength conversion is costly.

In the original design, when two bursts collide, the second burst is discarded entirely. Apparently, this design is inefficient and need not be the case. In [4], the authors proposed an approach to reducing an OBS switch's packet loss rate. In this approach, when the desired transmission times of two contending bursts overlap partially, one burst is chosen to be switched in its entirety while the other burst is allowed to be partially switched, with the overlapping part being truncated. Two different truncation schemes can be used. The first scheme is to cut the head of the second burst while the second scheme is to cut the tail of the first burst. They have different effects and require different protocols and processing. In [5], the author proposed an approach to using TCP congestion control scheme to significantly reduce the packet drop rate in an OBS network.

In NCTUns, to create an OBS network, a user just uses the optical burst switch tool button to add several OBS switches into the network and use the link tool button to connect them. Like in a circuit-switching optical network, optical edge routers must "sit" at the boundary of the OBS network to connect the OBS network with the outside non-optical fixed network. The following figure shows an example OBS network in NCTUns.

In an OBS network simulation case, unlike in a circuit-switching optical network simulation case, a user need not set up protection rings and specify the light paths between every pair of optical edge routers. This is because these schemes are not the focuses of the current OBS researches. When packets need to be sent from an optical edge router to another optical edge router, NCTUns OBS protocol modules will automatically choose the shortest path between them as their light path.

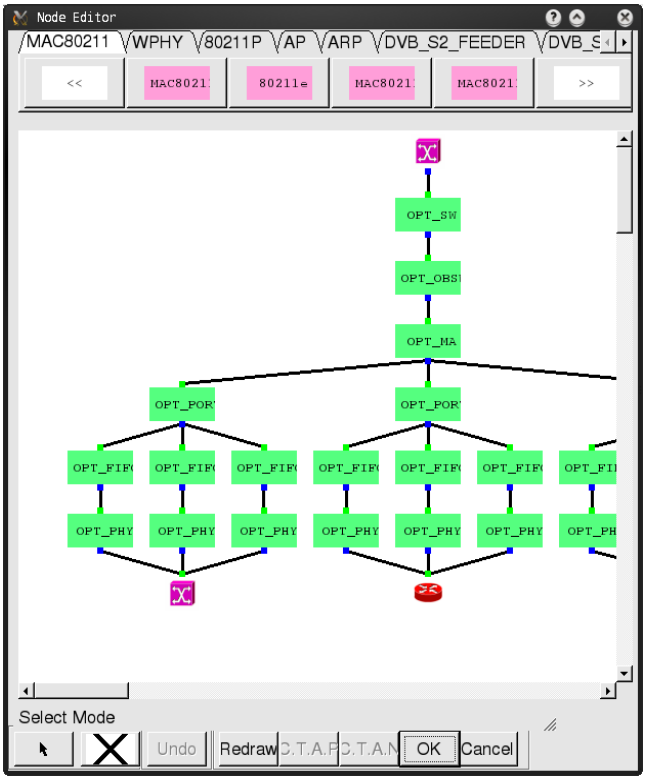


An example optical-burst-switching network.

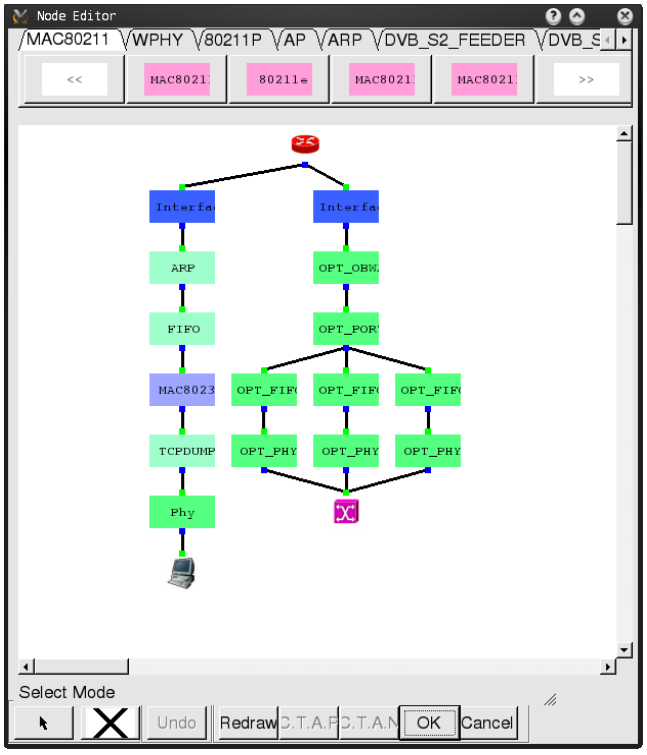
OBS Protocol Stack

In the following, we show the protocol stack of an optical burst switch and the protocol stack of an optical edge router in an OBS network. In this OBS network, an optical link has three wavelength channels.

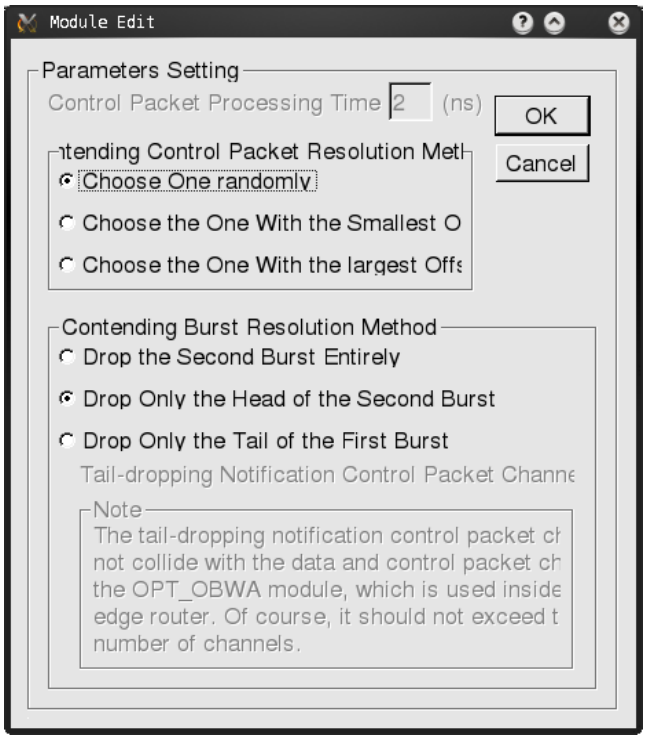
In the following, we show the parameter dialog box of the protocol module (OPT_OBSW) used inside the protocol stack of an optical burst switch. This protocol module deals with two things. First, when multiple control packets arrive exactly at the same time and they all contend for the same outgoing channel, it needs to decide which one to accept while discarding other ones because the optical burst switch can process only one control packet at one time. At present, three contention resolution methods are provided. In the first method, the module randomly picks one control packet. In the second method the module picks the control packet with the smallest time offset while in the third method the module picks the control packet with the largest time offset. Second, when two bursts contend and overlap with each other partially, it needs to decide how to deal with this situation. At present, three burst contention resolution methods are provided. In the first method, the module drops the second burst entirely. In the second method the module drops the head of the second burst while in the third method the module drops the tail of the first burst.



The protocol stack of an optical burst switch.



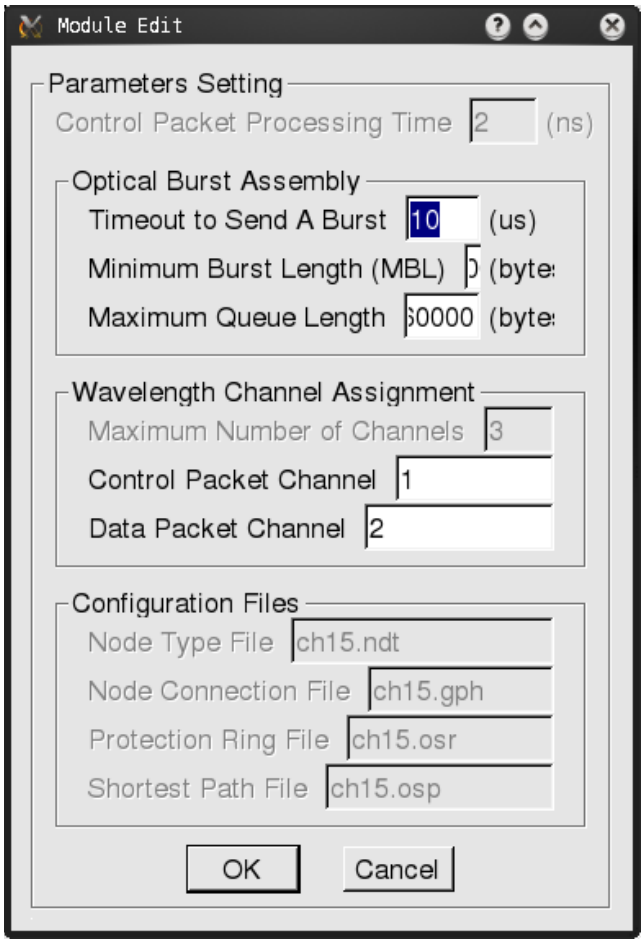
The protocol stack of an optical edge router used in an OBS



The parameter dialog box of the OPT_OBSW protocol module, which is used in the protocol stack of an optical burst switch.

In the following, we show the parameter dialog box of the protocol module (OPT_OBWA) used inside the protocol stack of an optical edge router in an OBS network. This module deals with burst assembly performed at an optical edge router. To assemble a burst, several packets need to be accumulated to make a burst large enough. The “Maximum Burst Length (MBL)” field specifies how many bytes of packets need to be accumulated before a burst can be sent out. To avoid too much delay, a short burst should still be sent out after a certain period of time even if its length is still less than MBL. The “Timeout to Send a Burst” field specifies this timeout period. When packets arrive at an optical edge router at a rate higher than the rate at which bursts can be sent out, they need to wait in a queue to be assembled. The maximum length allowed for this queue is specified by the “Maximum Queue Length” field. When a packet arrives but finds that the queue is full, it will be dropped.

In an OBS network, control packets and their burst data packets are sent over different wavelength channels. In this module, a user can specify these channels.



The parameter dialog box of the OPT_OBWA protocol module, which is used in the protocol stack of an optical edge router in an OBS network.

Summary

This chapter presents how to use NCTUns to conduct optical network simulations. NCTUns can be used to study traditional circuit-switching optical networks, where protection schemes and routing schemes are the main focuses. NCTUns can also be used to study newly-proposed optical burst switching networks, where burst contention resolutions, QoS, high link utilization are the main focuses. Readers should refer to optical network books and OBS papers to take advantage of NCTUns to conduct optical network simulations.

Reference

[1] C. Qiao and M. Yoo, “Optical Burst Switching (OBS) - A New Paradigm for an Optical Internet,” Journal of High Speed Networks, vol. 8, no. 1, pp. 69-84, Jan. 1999.

[2] S. Verma, H. Chaskar, and R. Ravikanth, “Optical Burst Switching: A Viable Solution for Terabit IP Backbone,” IEEE Network Magazine, Vol. 14, No. 6, pp. 48-53, November 2000.

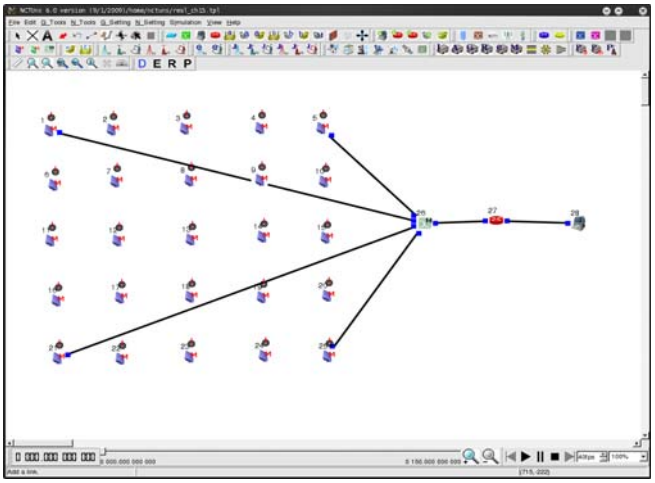
[3] M. Yoo, C. Qiao, and S. Dixit, “QoS Performance of Optical Burst Switching in IP-over-WDM Networks,” IEEE JSAC, Vol. 18, No. 10, pp. 2062-2071, October 2000.

[4] A. Detti, V. Eramo and M. Listanti, “Optical Burst Switching with Burst Drop (OBS/BD): An Easy OBS Improvement,” Proceedings IEEE ICC’02 (International Conference on Conference) April-May, 2002, New York, USA

[5] S.Y. Wang, “Using TCP Congestion Control to Improve the Performances of Optical Burst Switched Networks,” IEEE ICC’03 (International Conference on Communication), May 11-15 2003, Anchorage, Alaska, USA

15. IEEE 802.11(b) Wireless Mesh Networks

Wireless mesh network is composed of multiple WLAN access points that wirelessly forward mobile client stations' packets. Due to this architecture, this type of network requires low wiring costs, is decentralized, reliable, and resilient against access point failures. In this chapter, we present how to use NCTUns to simulate an IEEE 802.11(b) wireless mesh network.



Wireless Mesh Networks Concept

A wireless mesh network (WMN) is composed of mesh access points and standard infrastructure mode WLAN mobile client stations. A client station uses the standard IEEE 802.11(b) protocol to attach to and associate with a mesh access point for obtaining networking services. In NCTUns, two kinds of mesh access points are supported, which are mesh OSPF access point (running OSPF as the routing protocol) and mesh STP access point (running the Spanning Tree Protocol as the routing protocol).

In NCTUns, a mesh access point has two IEEE 802.11(b) wireless interfaces. The first one operates in the infrastructure mode to serve standard WLAN client stations while the second one operates in the ad-hoc mode to wirelessly forward packets among mesh access points. A WMN can connect to a fixed network such as an Ethernet or an optical network. In such a case, a mesh multi-gateway switch is needed to connect these two networks. The following figure shows a configuration of an OSPF WMN. In this network, the four mesh access points at the corners of the WMN connect to the fixed network on the right via a mesh multi-gateway switch. With this configuration, a client station in the WMN can exchange its packets with any host on the fixed network.

A WMN need not connect to a fixed network and can be a closed network by itself. In such a configuration, a client station cannot access information provided on the fixed network. However, client stations can exchange their information via the WMN. For example, they can make voice-over-IP phone calls among themselves on top of the WMN.

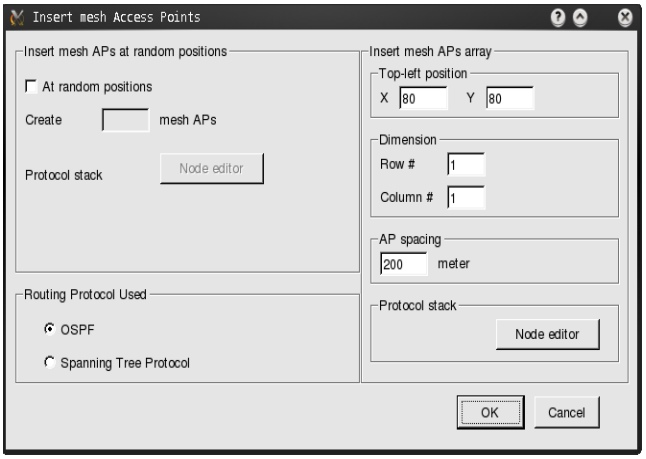
Setting Up Wireless Mesh Networks

In the following, we show how to set up a wireless mesh network.

Insert Mesh Access Points

A user can click one of the two mesh access point icons and place mesh access points in the working area one by one. In addition, a user can quickly insert multiple mesh access points by using the **Menu -> N_Tools -> 802.11(b) Wireless Mesh Network ->Insert 802.11(b) Mesh Access Points** command.

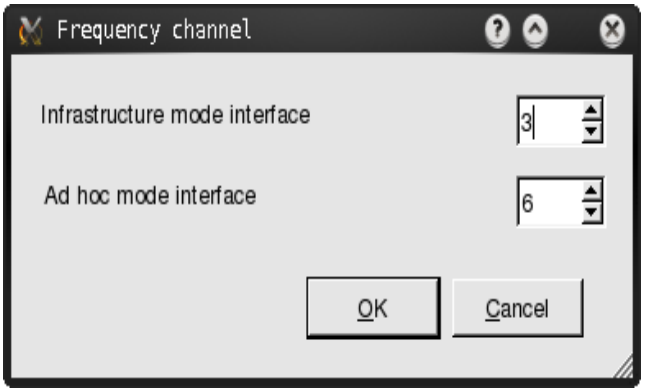
In the popped-up insertion dialog box shown below, a user can choose which type of mesh access point should be inserted, how many access points should be inserted, and which positioning style (random or array style), should be used. If a user wants to change the protocol stack of the mesh access points to be inserted, this job can be done here.



Set Dual-Radio Frequency Channels for Mesh AP

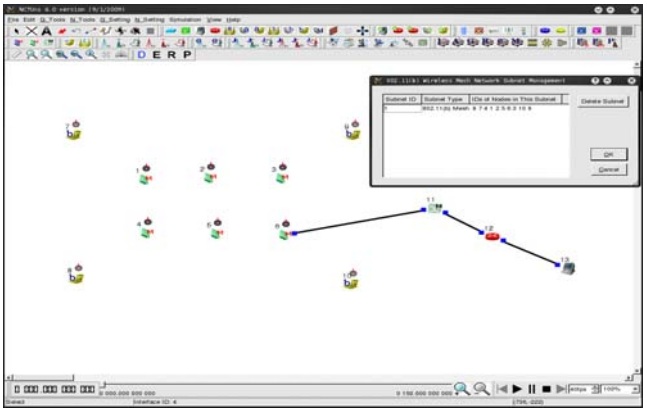
Each mesh access point has two wireless interfaces. One is operating in the ad-hoc mode while the other is operating in the infrastructure mode. By default, the infrastructure mode interface uses the same frequency channel as the default frequency channel used by an infrastructure mode mobile node. This configuration allows infrastructure mode mobile nodes to connect to mesh access points without any configuration change.

If a user wants to change this default setting for a few mesh access points, he (she) can enter the node editor of these mesh access points one by one to modify the frequency channel setting of the used WPHY modules. If many mesh access points need to be changed, a more convenient way is to execute the **Menu -> N_Tools -> 802.11(b) Wireless Mesh Network -> Specify Dual-Radio Frequency Channels for Selected Mesh APs** command on the selected access points. A dialog box shown below will pop up. In this box, a user can change the frequency channels for all selected mesh access points in just one step.



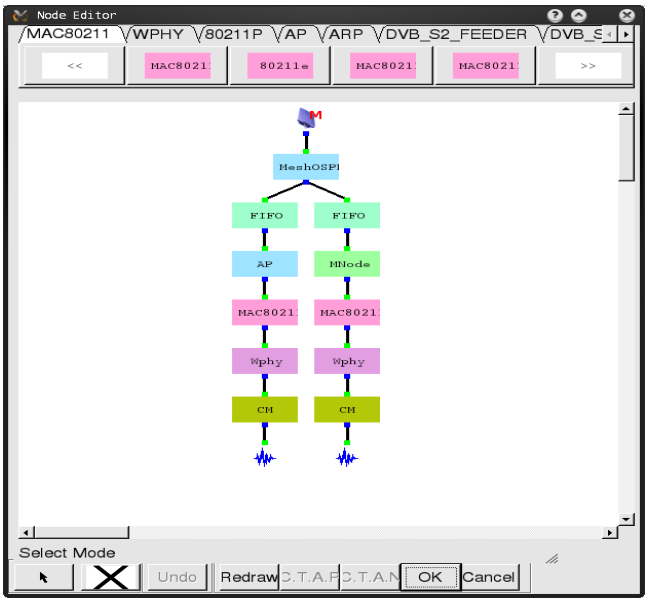
Form Wireless Subnet

After inserting 802.11(b) mesh access points and 802.11(b) infrastructure mode mobile nodes, a user must use the “Form wireless subnet” ( ) tool to select all such nodes to group them together to form a wireless subnet. Specifying this relationship enables the GUI program to automatically assign IP and MAC addresses to all of these nodes, saving much time and effort of the user. The formed 802.11(b) wireless mesh network subnets can be viewed and managed by executing the **Menu -> N_Tools -> 802.11(b) Wireless Mesh Network -> Manage 802.11(b) Wireless Mesh Network Subnets** command. The following figure shows the dialog box of this command.

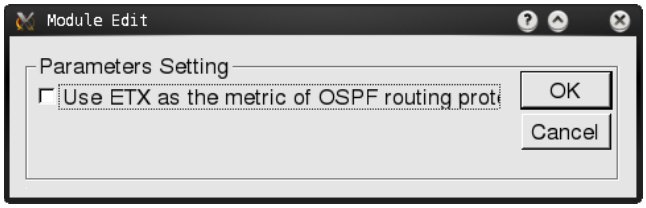


Wireless Mesh Network Protocol Stack

The following figure shows the protocol stack of the mesh OSPF access point.

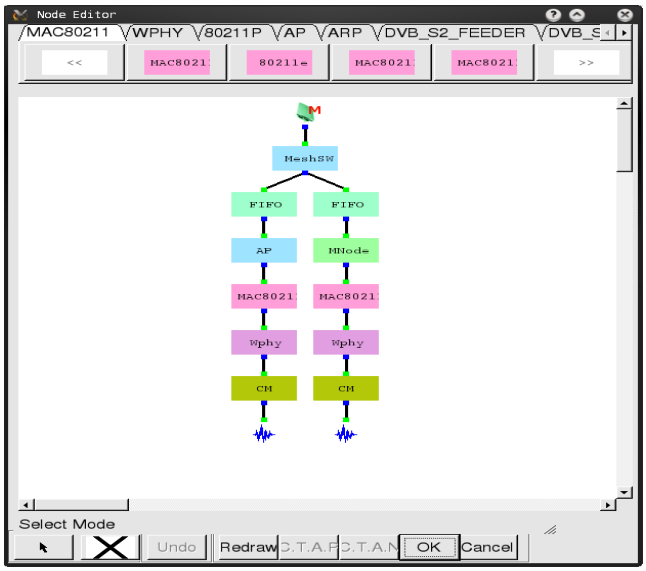


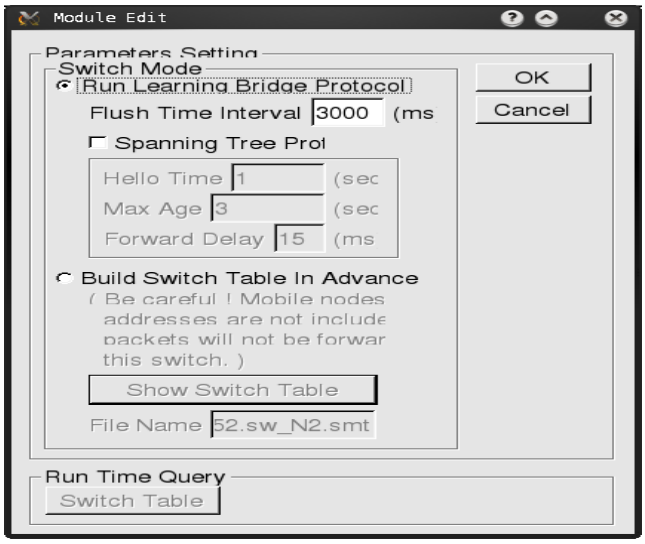
In the parameter setting dialog box of the MeshOSPF module, an option called "Use ETX as the metric of OSPF routing protocol" can be checked. The ETX stands for expected transmission count metric, which is a radio-aware routing metric for 802.11. It tries to find high-throughput paths on multi-hop wireless networks. The ETX metric incorporates the effects of link loss ratios, asymmetry in the loss ratios between the two directions of each link, and interference among the successive links of a path. It minimizes the expected total number of packet transmissions (including retransmissions) required to successfully deliver a packet to the destination. The following figure shows this dialog box.



The MeshOSPF module's parameter setting dialog box.

The following figures show the mesh STP access point's protocol stack and the MeshSW module's parameter setting dialog box. Mesh STP access points use the spanning tree protocol to build up a routing tree among mesh access points. This protocol is commonly used in switches on fixed networks to avoid packet-looping problems.





The MeshSW module's parameter setting dialog box.

Summary

This chapter shows how to set up a wireless mesh network on NCTUns. Nowadays NCTUns provides two kinds of mesh access points which are designed to run OSPF routing protocol and spanning tree routing protocols, respectively. Mobile devices can move around a wireless mesh network and use the mesh infrastructure to communicate with each other or connect to the Internet. A mesh multi-gateway switch should be employed to act as a bridge between a wireless mesh network and other fixed networks. In this mesh simulation environment, new mesh routing protocols and new mesh network applications can be developed and evaluated.

16. IEEE 802.11(e) QoS Networks

Wireless LANs (WLAN) provides the same best effort service as that provided on Ethernet. Although this service is good enough for data applications, it is inadequate for multimedia applications that demand quality of service (QoS). In order to provide service differentiations and QoS guarantees on WLAN, the IEEE 802.11 committee developed 802.11(e) specification. This chapter presents how to use NCTUns to simulate IEEE 802.11(e) QoS networks.

IEEE 802.11(e) Concept

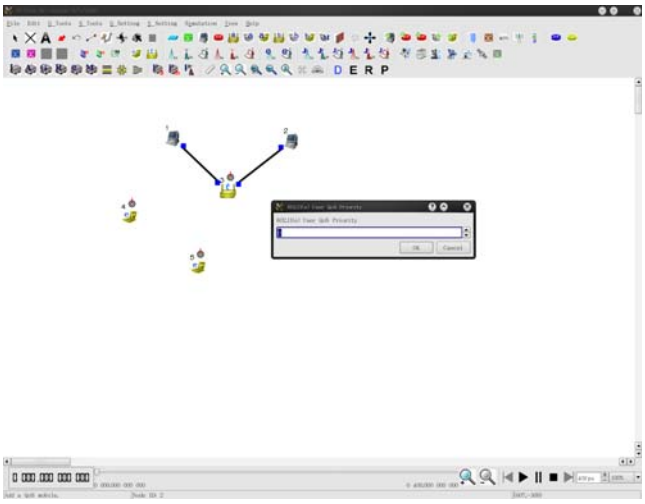
The 802.11(e) specification defines MAC protocols for QoS enhancements under the infrastructure mode. An access point allocates medium access opportunity to attached mobile stations according to their QoS demands during the contention-free medium access period. A mobile station needs to send a request to the access point to request a certain amount of bandwidth for its streaming data. If the request is granted, the access point will reserve bandwidth for it and give it enough medium access chances to transmit its data. This is done by polling the mobile nodes constantly to allow it to send out its packets. In NCTUns, the 802.11(e) packet scheduler and admission control unit are implemented based on the sample scheduler described in annex K 3.3 of IEEE Std 802.11e-2005.

An IEEE 802.11(e) Usage Example

The IEEE 802.11(e) mechanism is used in an infrastructure mode WLAN. To simulate an IEEE 802.11(e) WLAN network in NCTUns, the IEEE 802.11(e) access point and the IEEE 802.11(e) mobile node should be used.

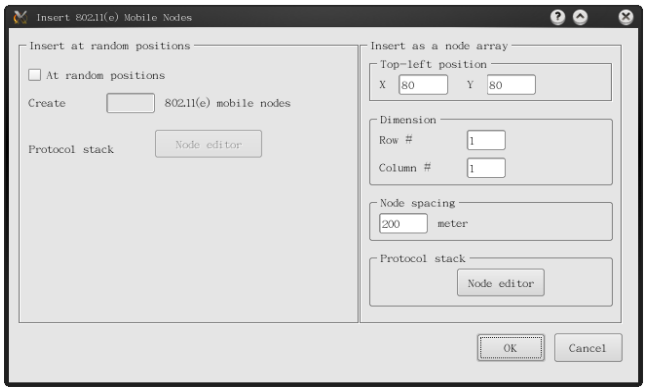
Insert 802.11(e) Mobile Nodes

When placing an 802.11(e) mobile node on the working area of the topology editor, a user is asked to input the user QoS priority for that mobile node. This declares each mobile node's medium access priority during the contention period.



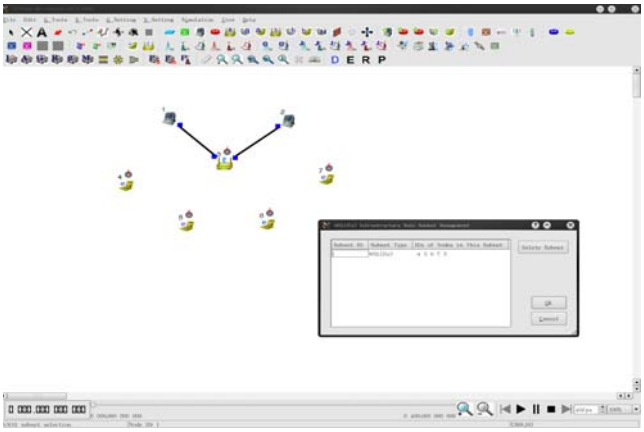
The user QoS priority needs to be set before an 802.11(e) mobile node can be placed on the working area of the topology editor.

If a user want to quickly place many 802.11(e) mobile nodes, he (she) can use the **Menu -> N_Tools -> 802.11(e) Wireless Network -> Insert 802.11(e) Mobile Nodes** command. In the insertion dialog box, a user can choose how many access points should be inserted and which positioning style (random or an array style) should be used. If a user wants to change the protocol stack of all inserted mobile nodes, he (she) can also do the change here.



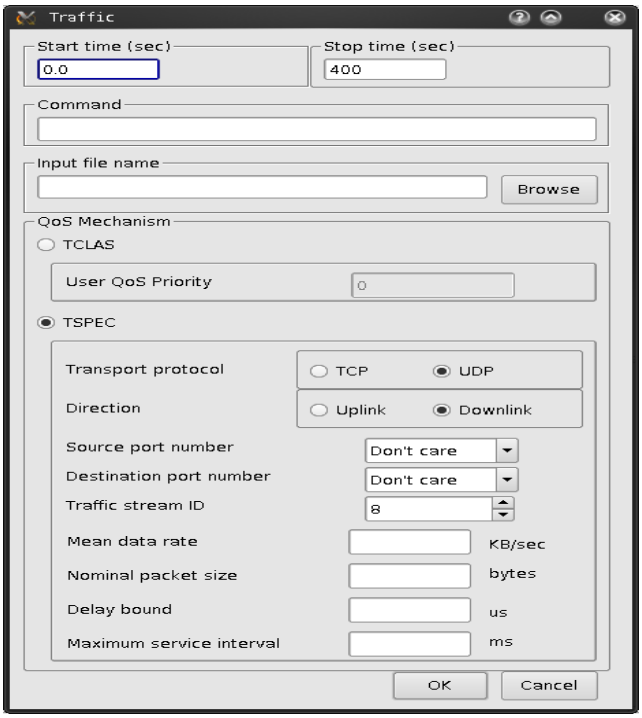
Insert multiple 802.11(e) mobile nodes at the same time to save time and effort

After inserting 802.11(e) mobile nodes, a user must use the "Form wireless subnet" ( ) tool to select all such nodes and the 802.11(e) access point to group them together to form a wireless subnet. Specifying this relationship enables the GUI program to automatically assign IP and MAC addresses to all of these nodes, saving much time and effort of the user. The formed 802.11(e) wireless subnets can be viewed and managed by executing the **Menu -> N_Tools -> 802.11(e) Wireless Network -> Manage 802.11(e) Infrastructure Mode Subnets** command. The following figure shows the dialog box of this command.



Configure Application with QoS Parameters

When a user specifies an application to be run on an 802.11(e) mobile node, the 802.11(e) QoS parameters demanded by this application should be specified. A user can click the Add button under the Application tab and then he (she) will see the QoS demand parameter configuration part at the bottom of the popped-up dialog box, which is shown below. The meanings of these parameters are defined in the 802.11(e) specification. A user needs to read the related 802.11(e) documents or specifications to understand the purposes of these parameters.



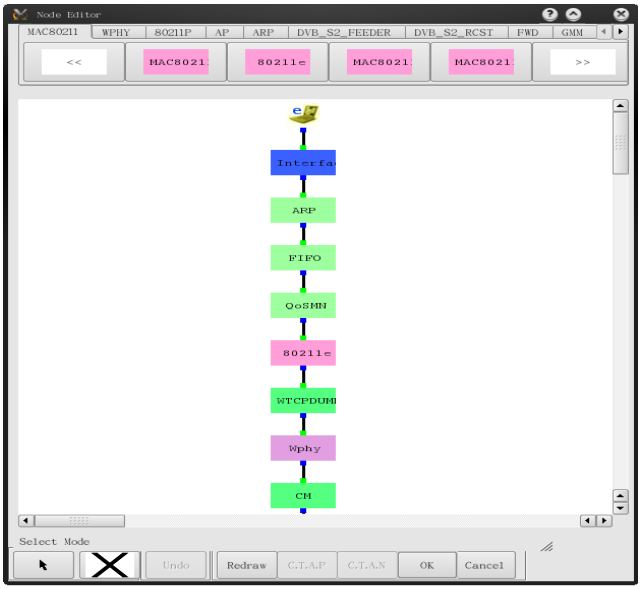
Specify 802.11(e) QoS parameters when adding an application

For example, suppose that a user wants to achieve a guaranteed 200 KB/sec UDP traffic flow from an 802.11(e) mobile node to the 802.11(e) access point and he (she) uses the "ttcp -t -u -s -p 8000 1.0.1.1" command to launch a greedy UDP traffic generator on that mobile node to send packets to another node with IP address 1.0.1.1. For this particular case, the user needs to choose the "TSPEC" (Traffic SPECification) option. In addition, the "Transport protocol" has to be set to UDP, the "Direction" has to be set to Uplink, the "Source port number" has to be set to "Don't care," the "Destination port number" has to be set to 8000, the "Traffic stream ID" has to be set to one of the values ranging from 8 to 15, the "Mean data rate" has to be set to 200 KB/sec, and the "Nominal packet size" has to be set to1024 bytes because the greedy UDP traffic generator sends packets with 1,024-byte data payload. Here, the "Delay bound" represents the maximum period of time from the arrival of a MSDU (Mac Service Data Unit) at the local MAC layer to the completion of the MSDU's transmission. The "Maximum service interval" is the maximum interval between the starts of two successive polling periods. According to the specification, if both of the "Delay bound" and the "Maximum service interval" are specified, only the latter will be used. If the user wants the access point to poll the mobile node every 20 ms, the "Maximum service interval" should be set to 20 ms and the "Delay bound" can be left empty.

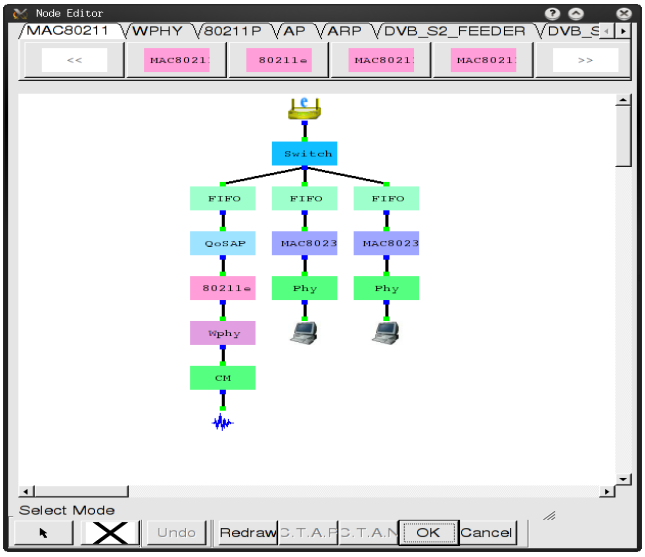
According to the sample scheduler described in annex K 3.3 of IEEE Std 802.11e-2005, the maximum data transmission period that can be granted to a traffic flow is 8,160 microseconds. This means that a mobile node cannot seize the medium for more than 8,160 microseconds to transmit its packets even though it may have many packets to transmit. If the access point has enough available bandwidth to satisfy the QoS demand of a traffic flow, the request will be granted. Otherwise, the request will be rejected.

IEEE 802.11(e) Protocol Stack

The following figures show the protocol stacks of the 802.11(e) mobile node and the 802.11(e) access point. The QoSMN and 80211e modules used inside the 802.11(e) mobile node do not need special parameter settings. Similarly, the QoSAP and 802.11e modules used inside the 802.11(e) access point do not need special parameter settings.



An 802.11(e) mobile node's protocol stack.



An 802.11(e) access point's protocol stack.

Summary

This chapter introduces how to set up an 802.11(e) QoS network. The most important step for enabling 802.11(e) QoS service is to specify QoS parameters. The QoS parameters are based on IEEE 802.11(e) specification. A user needs to understand the meanings of these QoS parameters for achieving correct simulation results. A user can easily develop and evaluate his (her) IEEE 802.11(e) scheduling mechanism on NCTUns.

17. Tactical and Active Mobile Ad Hoc Networks

Tactical and active mobile ad hoc network (MANET) is characterized by network nodes that can move actively in response to the current conditions of the environment. In such a network, each network node is equipped with a wireless radio to communicate with each other to share its locally-collected information. Using the knowledge of the shared information, each network node is able to move in a coordinated manner for some objectives, such as chasing a target node, exploring the undiscovered area, and so on.

A tactical MANET Scenario

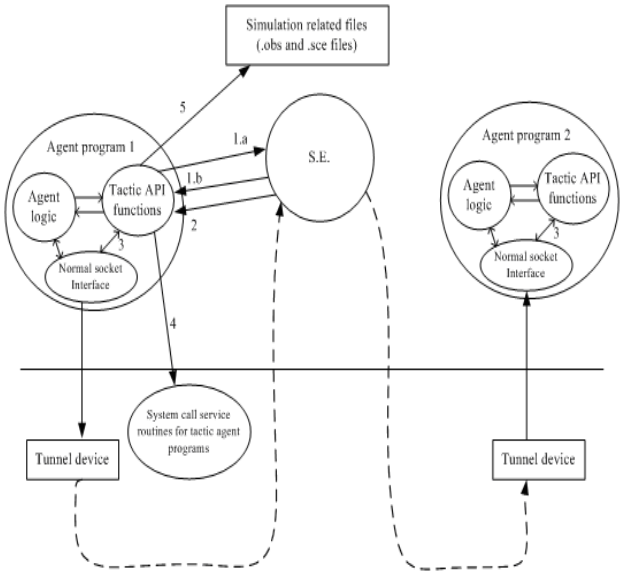
Take a tactical MANET as an example, suppose that there are several chasing nodes and one target node in such a network. Each chasing node first moves towards a random position and tries to detect the position of the target node. The chasing nodes periodically use their radios to share their locally-collected position information of the target node. Upon receiving the position information of the target node, a chasing node makes a tactical strategy for capturing the target node. For instance, they may move along a specific direction for chasing the target node or adopt a more sophisticated strategy to siege the target node.

Since mobile nodes in a tactical mobile ad hoc network can move "actively," such networks are also viewed as one type of active networks. Besides the tactical mobile ad hoc network, there are various kinds of active networks, for example, the vehicular network, the active sensor network, etc.

Tactical and Active MANET Simulation

Nowadays many tactics have been proposed for various objectives based on different battlefield situations. Each of them may use a different heuristic or policy. Due to the diversity and the complexity of various tactical policies, integrating such policies into the simulation engine will complicate the design of the simulation engine and make it unmanageable. To overcome this problem, NCTUns uses the following design principles to support tactical and active MANET simulations.

In NCTUns, the tactical policy is separated from the underlying mechanism. A user-level program, referred to as a "tactical agent program," is responsible for making tactical decisions and controlling the behavior of the mobile node on which the agent is running. The simulation engine is responsible for providing agents with essential services, such as obtaining the current position of a node on which an agent is running, agent-to-agent communication, and so forth.



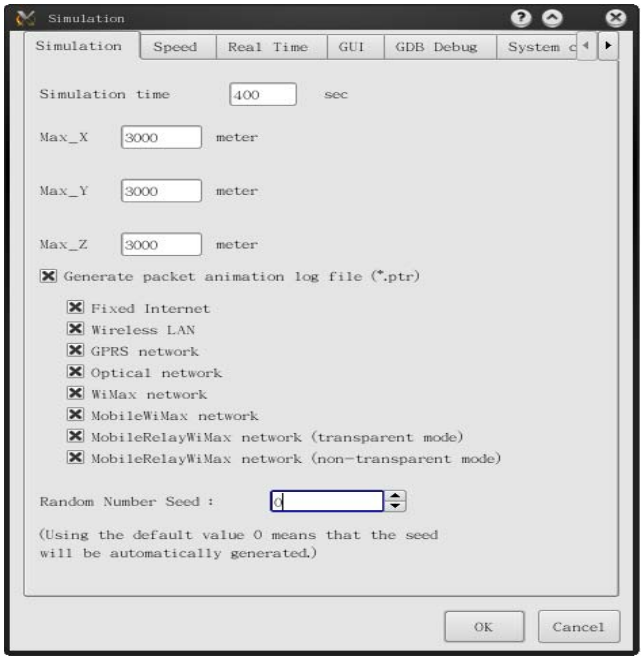
The architecture of NCTUns for supporting tactical and active MANET simulations

In the above figure, the agent logic contains the core statements of an agent program. It performs some specific tasks such as making a strategy based on the current conditions of the battlefield. The tactical API functions have to be included in an agent program to provide the agent logic with the essential services. According to the purposes of these tactical API functions, the tactical API functions can be categorized into five different groups, each of which is represented by a numbered arrow in the above figure. The detailed explanations of these API functions are available in "The Protocol Developer Manual for the NCTUns 6.0 Network Simulator and Emulator" document.

The Simulation Field and Mobile Node

The field of a simulation is the space within which mobile nodes are allowed to move around. A battlefield is defined as an area within which members of forces such as soldiers,

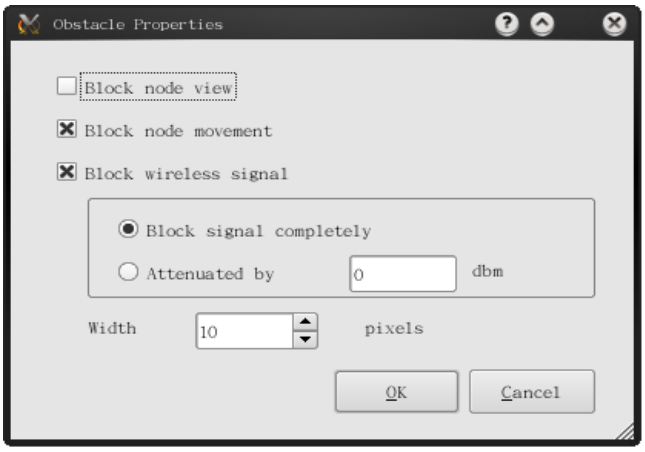
tanks, etc. can move to perform military operations. As such, the field of a simulation can be viewed as the battlefield of a campaign, and the members of forces can be viewed as mobile nodes moving on the simulation field. The field is usually defined by a rectangle, specified by its length and width. As shown in the following figure, under the **[Simulation]** tab, which is in **Menu -> G_Setting -> Simulation,** the attributes of the simulation field can be specified.



A force member in a battlefield can be modeled and simulated by a mobile node in a tactical mobile ad hoc network. Each mobile node needs to specify an agent program to be run on it. One can open the mobile node's dialog box and then specify such an agent program under the **[Application]** tab.

Obstacle

An obstacle is an essential component used to model a real battlefield. In NCTUns 6.0, an obstacle has four important attributes, which can be set by double-clicking an obstacle. The default values for these attributes can be set by executing the **Menu -> G_Setting -> Obstacle** command. The first attribute is the **width** of this obstacle. The second one is the "**block node view**" property, namely, whether an obstacle blocks the view of nodes or not. If this property is enabled, the obstacle should block the line-of-sight of network nodes during the simulation. The third one is the "**block node movement**" property. If this property is enabled, the obstacle should block the movements of mobile nodes. The final one is the "**block wireless signal**" property. If this property is enabled, the obstacle will block a passing wireless signal or attenuate its strength by the amount specified. The following figure shows the dialog box of an obstacle in the NCTUns GUI program.



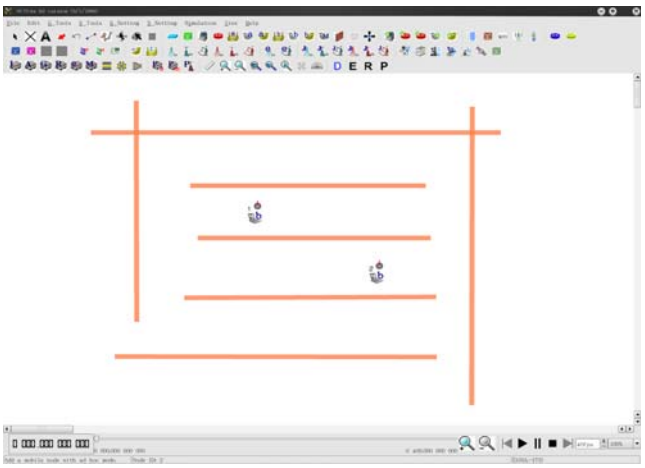
In the dialog box, there are three check boxes related to the three properties mentioned above. Note that if "**block wireless signal**" property is enabled, i.e., the "**Block wireless signal**" option is checked, one of the two options, "block signal completely" and "attenuation by $x dbm" in the following box should be set, where $x denotes the amount of the signal strength attenuation. If the first option is set, this obstacle will block the wireless signal completely, that is to say, the wireless signal cannot pass through this obstacle at all. If the second option is set, the amount of signal strength attenuation caused by this obstacle should be specified. At the end of the obstacle dialog box is the field used to specify the width of the obstacle in pixel.

An Example of Tactical MANET Simulation

In the following figure, one can see a scenario of the tactical mobile ad hoc network. There are two mobile nodes located in a maze filled with many obstacles. One mobile node is the chasing node while the other is the target node.

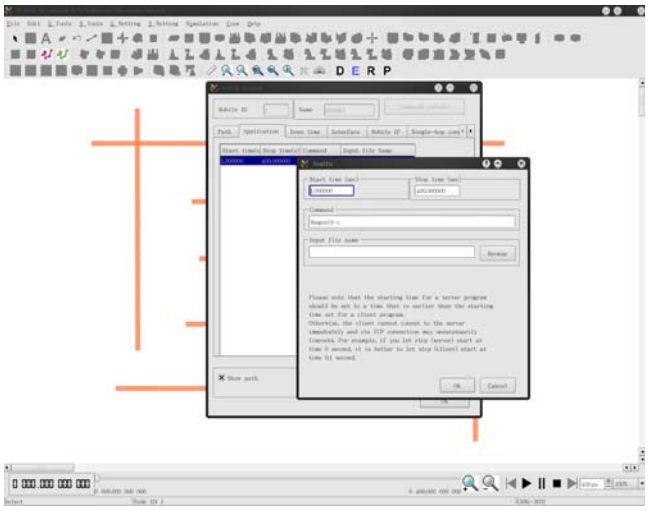
Specify a Tactical Agent Program for Each Mobile Node

For each mobile node, one has to specify a tactical agent program running on it via the **[Application]** tab, which is in the node's dialog box. For example, as shown in the following figure we specify that the Magent5-c agent should be run on node 1 during the simulation. Right now the



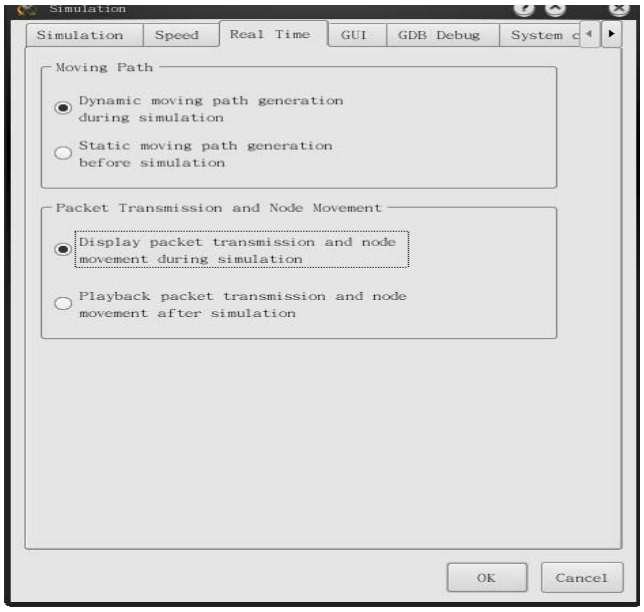
An example network in which a chasing node wants to chase a target node.

supported tactical agent programs are named Magent1, Magent2, Magent3, Magent4, and Magent5-c and Magent5-t. Each of these tactical agent programs uses a different tactical strategy and all of them are installed in the default /usr/local/nctuns/tools directory.



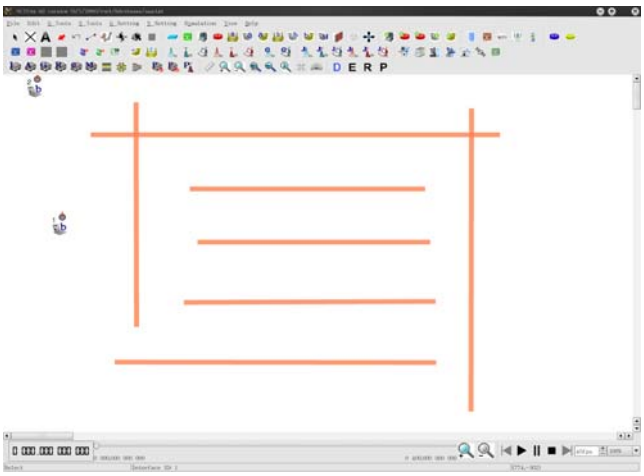
Simulation Settings for tactical MANET Simulation

Before one can start a tactical MANET simulation in NCTUns, it is important to enable two options under the **[Real Time]** tab, which is in **Menu -> G_Setting -> Simulation**. As shown in the following dialog box, there are two important options that should be set before a tactical MANET simulation is started. The first one is the "**mode of moving path generation**" option. For a tactical MANET simulation, one should set the option as "Dynamic moving path generation during simulation" to indicate to the simulation engine that a mobile node's moving path will be generated dynamically. If the "static moving path generation before simulation" mode is chosen, a mobile node's moving



path is predetermined by the static path specified in the scenario description file (.sce file), which is the default mode for non-tactical MANET simulation cases.

The second important option is "**the mode of displaying packet transmission and node movement**." If this option is set as "display packet transmission and node movement during simulation," then the GUI program will run-time display the packet transmission and node movement when the simulation is running. The following figure is a snapshot of the GUI program when it displays the node movement at run time. If this option is set as "playback packet transmission and node movement after simulation," then the GUI program will not display any packet transmission and node movement during simulation. Instead, it replays the packet animation file (.ptr file) after the simulation is finished.



The run-time display of node movement and packet transmissions during a tactical MANET simulation

Summary

In this chapter, we give a conceptual introduction to the tactical and active mobile ad hoc network, an example scenario of such a network, and how NCTUns supports tactical and active mobile ad hoc network simulations. Besides, we explain the attributes of an obstacle, which is an essential component used to model a battlefield in the real world. Finally, we illustrate the necessary operational steps for running up a tactical and active mobile ad hoc network simulation in NCTUns.

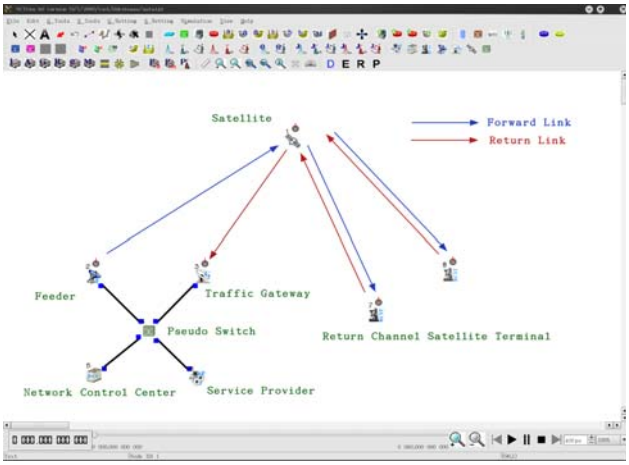
18. DVB-RCS Satellite Networks

DVB-RCS (Digital Video Broadcasting - Return Channel Via Satellite) is a well known standard providing channels for a GEO Satellite to interact with fixed RCSTs (Return Channel Satellite Terminals) on the ground. A DVB-RCS system enables two-way data exchanges between service providers and end users. As such, Internet protocols such as TCP/IP and UDP/IP can operate in DVB-RCS systems.

Network Nodes

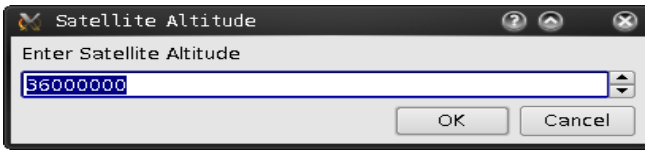
The following figure shows (from left to right) the seven kinds of network nodes comprising a DVB-RCS network: SP (Service Provider), NCC (Network Control Center), RCST (Return Channel Satellite Terminal), Feeder, TG (Traffic Gateway), Satellite, and Pseudo Switch.

The NCC is the central controller of the whole DVB-RCS network. It is responsible for managing the use of the channel resource on the forward link and the return link. The SP is the gateway that interconnects a DVB-RCS network and any kind of supported networks in NCTUns. In other words, any network traffic generated from a RCST has to be routed to external networks through the SP and vice versa. The TG is the gateway that receives return-link signals issued by the RCSTs. It is responsible for delivering the signals to the NCC and the SP. The Feeder is responsible for issuing forward-link signals that contain management and data messages sent from the NCC or the SP. The Pseudo Switch is a virtual node that does not really exist in a DVB-RCS network. It is used in the NCTUns's GUI program to graphically interconnect a NCC, a SP, a Feeder, and a TG. During simulation, transmitted messages are exchanged directly from the NCC/SP to the Feeder or from the TG to the NCC/SP, and they do not pass through the Pseudo Switch at all. The Satellite is a GEO satellite with transparent transponders. In other words, it is just a signal repeater. The Satellite receives the signals from uplink channels, amplifies them, and transmits them on the downlink channels. The RCST can be used as an independent terminal device or as the gateway to a closed network such as an enterprise Intranet or a remote LAN. The only communication paths that a RCST has are the forward link and the return link provided by the satellite infrastructure. The following figure shows an example DVB-RCS network.



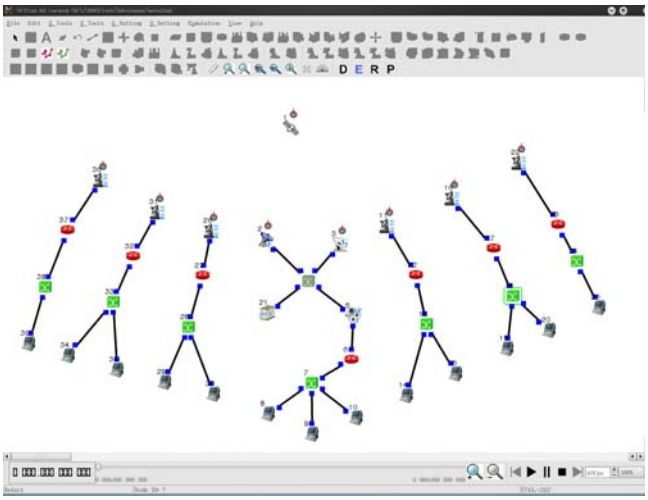
A DVB-RCS network with seven kinds of network nodes

When placing a satellite node in the working area, one will see a popped-up dialog box. The altitude of the satellite can be specified in this dialog box.



Extended Network Topology

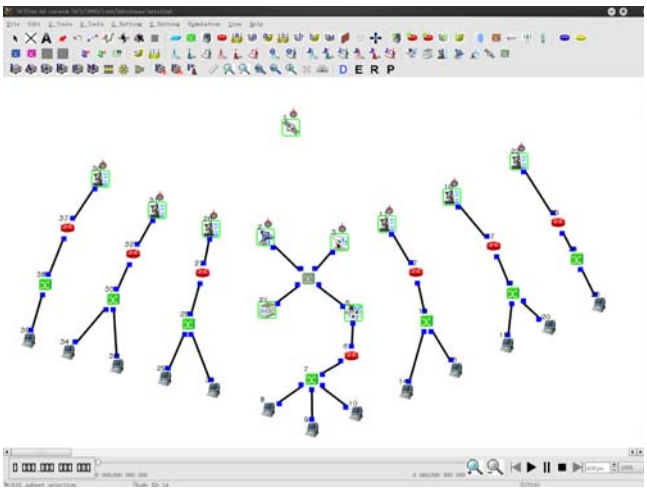
The following figure shows an extended network topology based on a DVB-RCS infrastructure. In this figure, one sees that a fixed network is attached to the SP and a LAN is attached to each RCST.



An extended DVB-RCS network

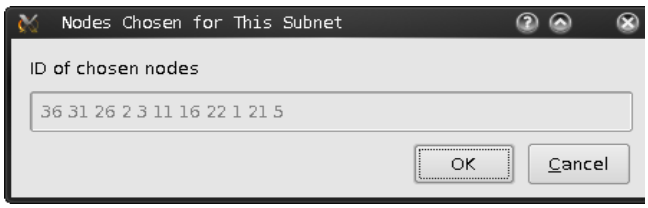
Subnet Formation

After setting up the desired network topology, one has to specify the subnet scope of a DVB-RCS network so that the GUI program can automatically assign an IP address to every layer-3 network interface. To do so, one first left-clicks the "form subnet" icon on the tool bar, then in turn left-clicks all required nodes to form a DVB-RCS network. The required nodes include one Satellite node, one TG node, one Feeder node, one NCC node, one SP node, and one or multiple RCST nodes. After left-clicking all of the required nodes, one can right-click the mouse to complete the subnet formation process. The following figure shows an example operation of the "Form Subnet" operation.

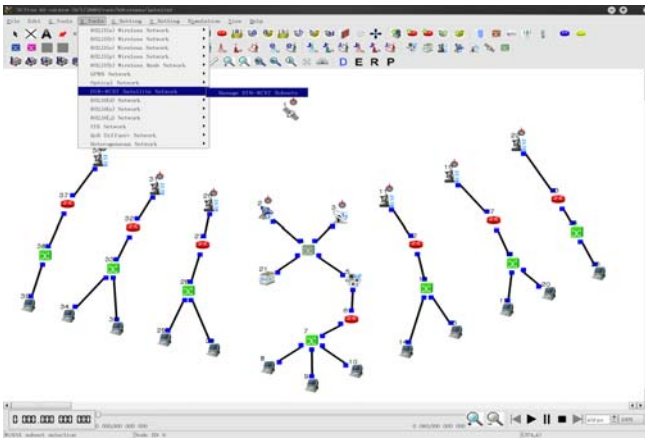


A "Form Subnet" example in which one Satellite node, one TG node, one Feeder node, one NCC node, one SP node, and two RCST nodes are selected to form a DVB-RCS subnet.

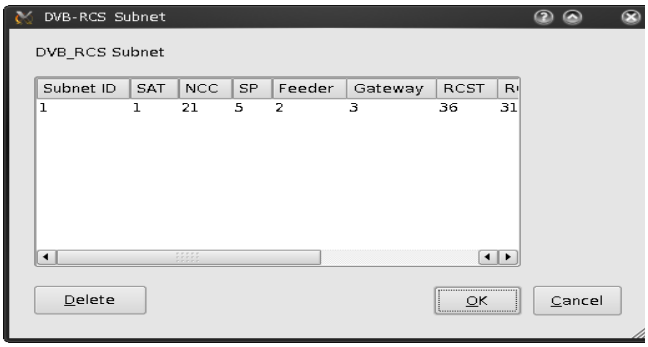
After right-clicking the mouse to end the subnet formation process, one can see a popped-up dialog box showing the node ID of every selected node. One can click the **OK** button to confirm this formation or click **Cancel** button to cancel this formation.



After the DVB-RCS subnet formation has been completed, one can check the formation results and delete any formed subnet by using the **Menu -> N_Tools -> DVB-RCST Satellite Network -> Manage DVB-RCST Subnets** command. The following figure shows where this command is located.



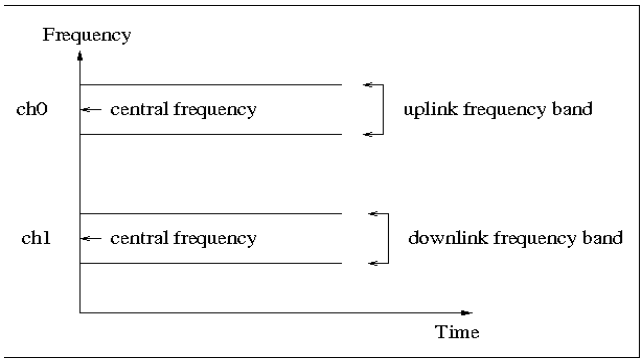
In the popped-up subnet management dialog box, one can see the node IDs of the nodes belonging to a subnet. One can choose an existing subnet from this dialog box and delete it by clicking the **Delete** button.



Channel Assignment

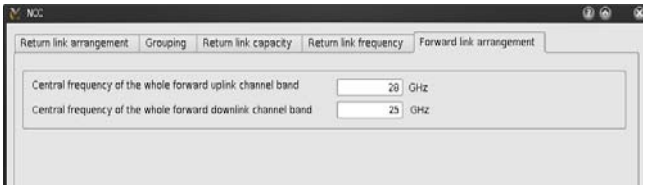
In a DVB-RCS system, the forward link and the return link are employed to provide two-way data exchanges between service providers and end users. One has to complete the channel-related configurations for these two links.

In the current implementation of DVB-RCS, only one channel is used on the uplink of the forward link, and also only one channel is used on the downlink of the forward link. Like that shown in the following figure, one has to assign the central frequencies for both of the uplink and downlink frequency bands. The value of the central frequency will be used to calculate the BER (Bit Error Rate) on the uplink/downlink when a simulation is running. The whole uplink frequency band is automatically designated as channel 0, and the whole downlink frequency band is automatically designated as channel 1. The following figure shows the forward link channel assignment used in NCTUns.

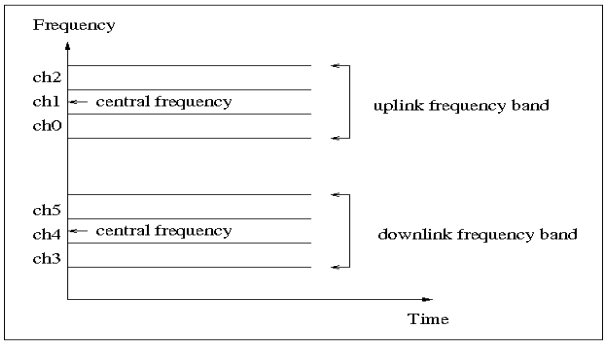


Forward link channel assignment

To set the value of the central frequency, one has to first change the operating mode from **Draw Topology** to **Edit Property**, and then double-click the NCC node. In the following popped-up dialog box, one has to choose the tab of **Forward link arrangement**. On this tab, one can set the values of the central frequency for the forward downlink and uplink channels.



Unlike the forward link, multiple channels are allowed to be used on the return link. The following figure shows the return link channel assignment.

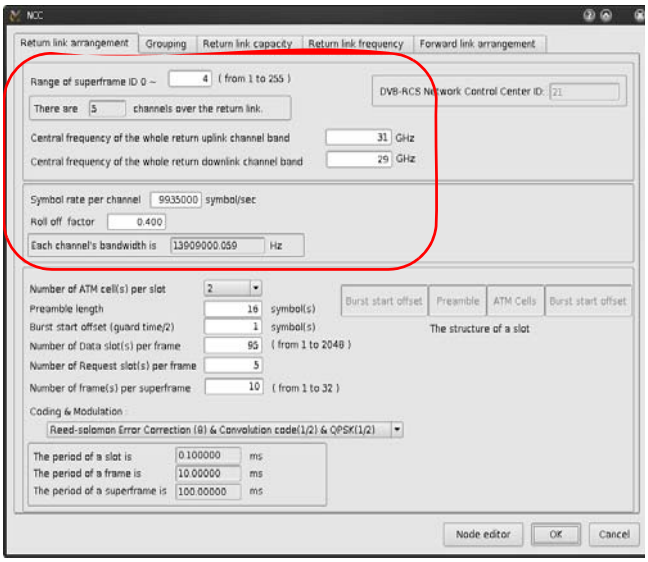


Return link channel assignment

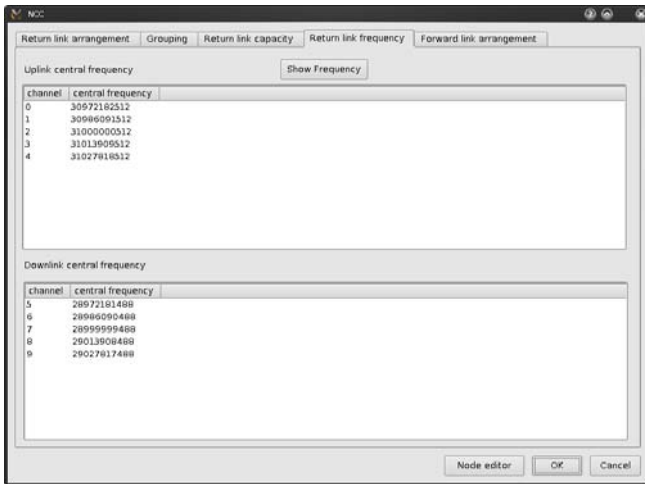
For the return link, one has to assign the central frequencies for the whole uplink and downlink frequency bands. In addition, one has to specify the bandwidth of each channel so that the central frequency of each channel can be derived automatically by the GUI program. The bandwidth of each channel is the same in the current implementation. The value of the central frequency of each channel will be used to calculate the BER (Bit Error Rate) on the uplink/downlink when a simulation is running. The channel ID (e.g., ch0, ch1, ch2, etc.) is automatically designated by the GUI program.

To set the central frequency and the channel bandwidth, one needs to double-click the NCC node. In the popped-up dialog box shown below, one has to choose the tab of **Return link assignment**. On the top half of this tab, one has to set the range of superframe ID. The number of superframes determines the number of channels used on the uplink/downlink of the return link. One also has to set the central frequencies for the whole uplink and downlink frequency bands. The bandwidth of each channel is determined by setting the symbol rate and roll off factor applied on each channel. The resulting value of each channel's bandwidth is calculated by the following equation.

*bandwidth = symbol rate * (1 + roll off factor)*

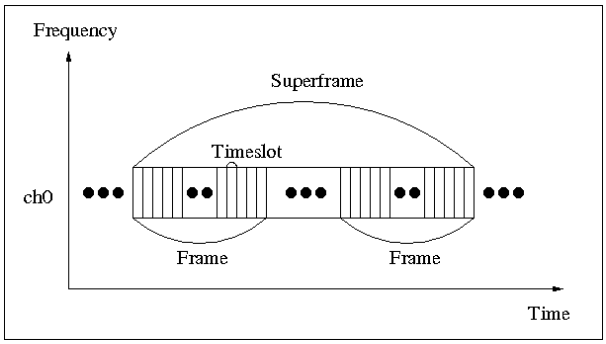


The automatically-generated central frequency of each channel is displayed on the tab of **Return link frequency**, which is shown below. Each time when one changes the central frequency of the whole uplink/downlink frequency band or the channel bandwidth, one should click the **Show Frequency** button on this tab to re-calculate the central frequency of each channel. The resulting values will be shown on this tab.



Return-link Channel Framing

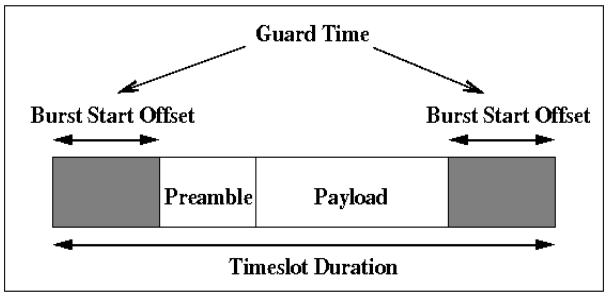
According to the DVB-RCS standard [1], the time domain of each channel on the return link is divided into consecutive superframes. In turn, each superframe is divided into frames. Finally, each frame is divided into timeslots. The following figure shows the framing structure applied on a return-link channel.



Superframes, frames, and timeslots on a return-link channel

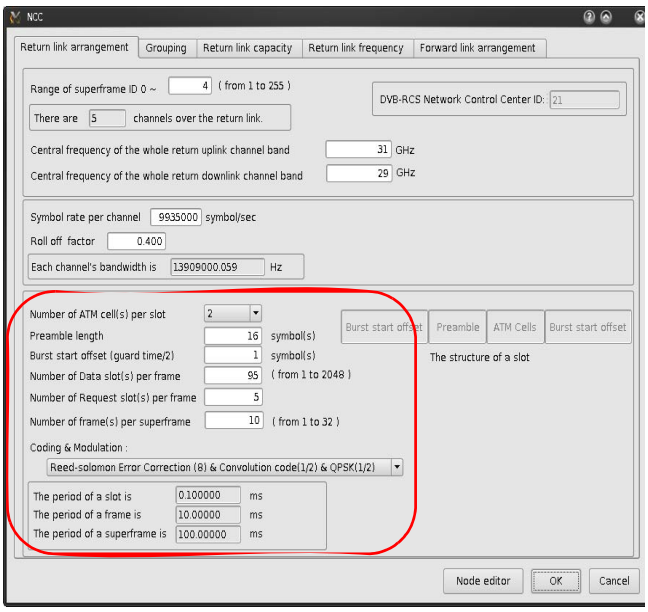
Like what is shown in the following figure, a timeslot is composed of a preamble duration, a payload duration, and a guard time duration. The guard time duration is split into two "burst start offset." One "burst start offset" is located at the head and the other one is located at the end of a timeslot. One, two, or four ATM cell(s) may be carried in the payload portion within a timeslot.

One has to set the number of ATM cells carried in a timeslot, the preamble length, the burst start offset (which is a half of the guard time period), the number of timeslots per frame used for bearing data (called "data slots" here), the number of timeslots per frame used for bearing capacity request (called "request slots" here), the number of frames per superframe, and the used combination of coding and modulation scheme. With the above information, the GUI program can



automatically calculate the periods of a timeslot, a frame, and a superframe. In addition, the maximum channel transmission capacity can be calculated by the GUI program.

To set the values of the above-mentioned parameters, one has to double-click the NCC node. In the popped-up dialog box shown below, one has to choose the tab of **Return link assignment**. The desired values should be set on the bottom half of the tab.



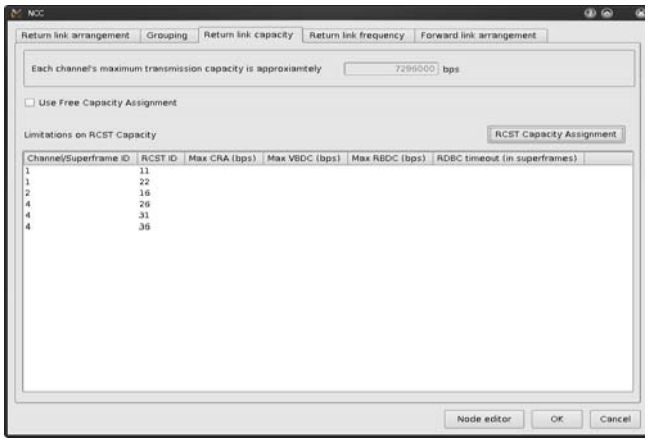
The resulting maximum channel transmission capacity can be viewed on the tab of **Return link capacity**. The following figure shows the dialog box of this tab. The usage of this tab will be described later.

The formulas for calculating the periods of a timeslot, a frame, and a superframe and the maximum channel transmission capacity are described below.

<Definitions>

SR: the symbol rate

N_ATM: the number of ATM cell per timeslot



B_ATM (53 bytes): the length of a ATM cell (5 bytes for header and 48 bytes for data payload)

RS (16 bytes): additional parity-check bytes appended to the original data by using Reed-Solomon outer coding

CC (2): the multiple on the increase of data length when using Convolutional Coding with 1/2 coding rate

QPSK (2): the number of bits per symbol when using QPSK modulation

PREAMBLE (symbols): the preamble length of a timeslot

GUARD (symbols): the guard time period of a timeslot

N_DATA_SLOT: the number of data timeslots per frame

N_REQ_SLOT: the number of request timeslots per frame

N_FRAME: the number of frames per superframe

PAYLOAD_SYMBOL: The number of symbols required to bear the payload of a timeslot

TIMESLOT: the period of a timeslot

FRAME: the period of a frame

SUPERFRAME: the period of a superframe

<Formulas>

PAYLOAD_SYMBOL = {[(**B_ATM** * **N_ATM**) + **RS**] * **CC** * 8 * (1/**QPSK**)}

TIMESLOT (ms) = [(**PAYLOAD_SYMBOL** + **PREAMBLE** + **GUARD**) / **SR**] * 1000

FRAME (ms) = **TIMESLOT** * (**N_DATA_SLOT** + **N_REQ_SLOT**)

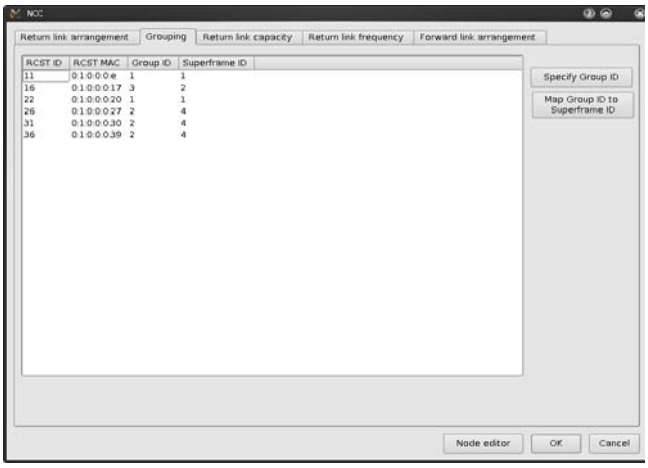
SUPERFRAME (ms) = **FRAME** * **N_FRAME**

The maximum channel transmission capacity (bps) = [**N_DATA_SLOT** * **N_ATM** * (**B_ATM** - 5)] / (**FRAME** / 1000)

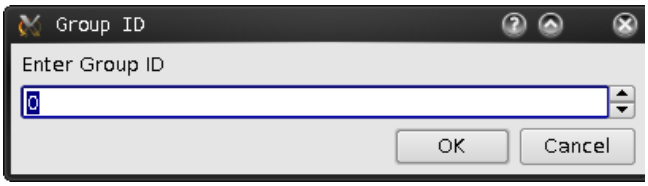
RCST Grouping

Each RCST has to be assigned into a group and each group is assigned a unique group ID. The RCSTs belonging to the same group use the same channel for transmission on the return link. Each channel is assigned an unique channel (superframe) ID. Multiple groups of RCSTs can share the transmission capacity of the same channel. In other words, the relationship between group IDs and superframe IDs can be a many-to-one mapping.

To specify the mapping, one has to double-click the NCC node. In the popped-up dialog box shown below, one has to choose the tab of **Grouping**. On the right-hand side of the tab, two buttons are provided for group-ID assignment and Group-ID-to-Superframe-ID mapping.

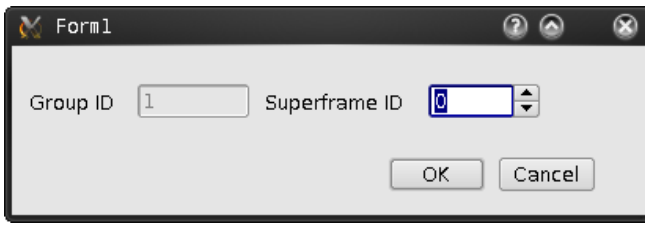


Before clicking the **Specify Group ID** button, one has to first choose a RCST whose group ID is to be specified. The following figure shows the popped-up dialog box after one clicks the **Specify Group ID** button. The group ID of the selected RCST can be set in this dialog box.



Before clicking the **Map Group ID to Superframe ID** button, one has to first choose one RCST whose group ID is to be mapped to a superframe ID. The following figure shows the popped-up dialog box after one clicks the **Map Group ID to Superframe ID** button. The group ID of the

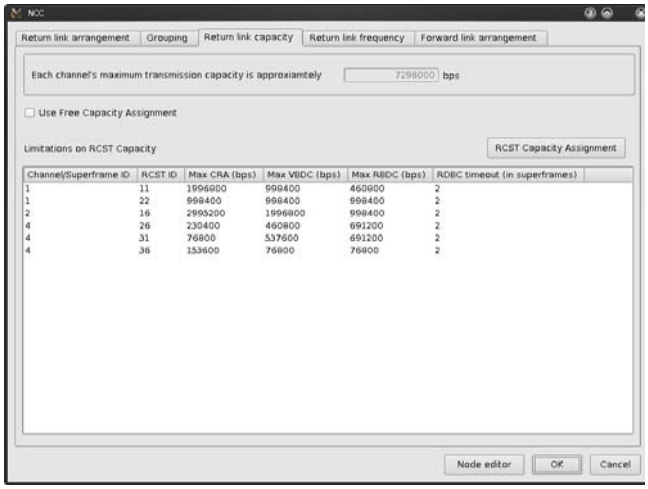
selected RCST is displayed only for reference and cannot be modified. One then chooses the desired superframe (channel) ID that the shown group ID should be mapped to.



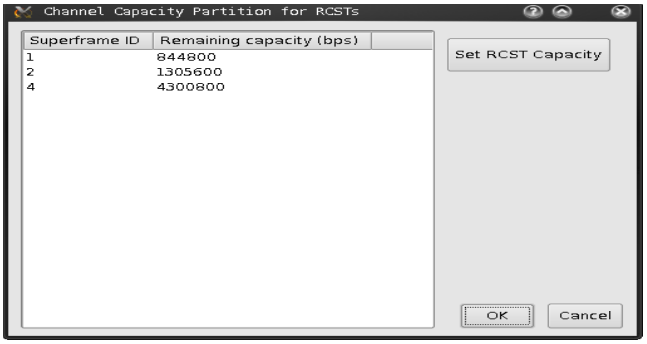
Channel Capacity Assignment

As mentioned before, the maximum capacity of each return link channel is determined by the parameters entered into the dialog box of the tab of Return link arrangement. The tab can be popped up by double-clicking the NCC node. The channel capacity can be allocated to every group of RCSTs that is assigned to use the transmission capacity of the channel. In other words, the total capacity of a given channel can be allocated to all RCSTs that issues/receives signals on the channel.

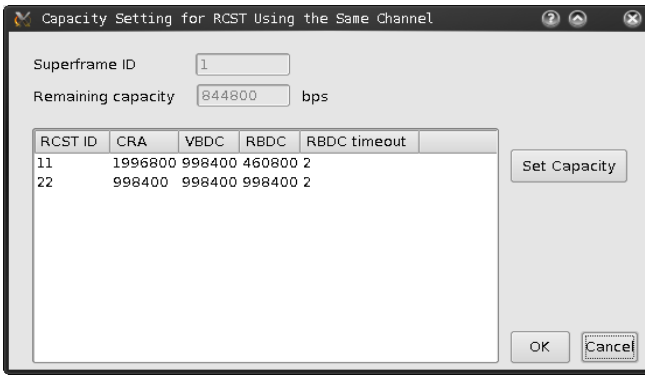
The channel capacity assignment can be operated on the tab of **Return link capacity**, which can be popped up by double-clicking the NCC node. As mentioned before, each channel's maximum transmission capacity is shown on the top of the tab. One can refer to the maximum channel capacity when starting to assign a certain amount of capacity to each RCST. To start RCST capacity assignment, one has to click the **RCST Capacity Assignment** button.



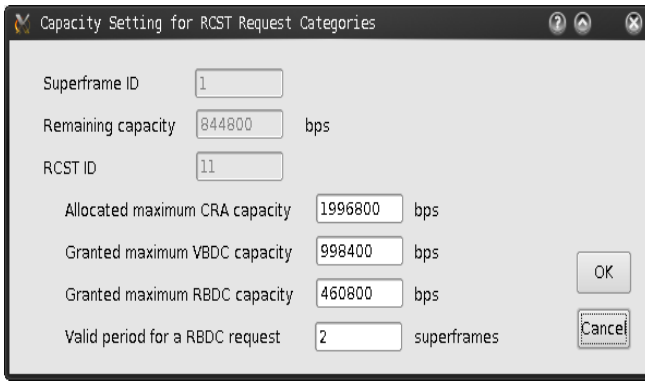
The following figure shows the popped-up dialog box when clicking the **RCST Capacity Assignment** button. In this box, the remaining capacity of each channel is shown. The remaining capacity is the channel capacity that can still be allocated to RCSTs. After choosing one superframe/channel ID, one can click the **Set RCST Capacity** button to allocate capacity to every RCST issuing/receiving signals on the selected channel.



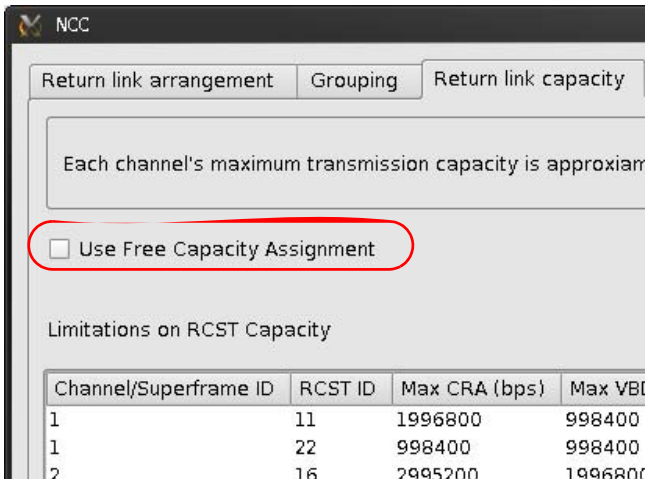
The following figure shows the popped-up dialog box when clicking the **Set RCST Capacity** button. This box shows the current capacity assignments for all RCSTs that issue/receive signals on the given channel. If one wants to change the assignment, he (she) can click the **Set Capacity** button.



According to the DVB-RCS standard [1], five capacity request categories are proposed: CRA (Continuous Rate Assignment), RBDC (Rate Based Dynamic Capacity), VBDC (Volume Based Dynamic Capacity), AVBDC (Absolute Volume Based Dynamic Capacity), and FCA (Free Capacity Assignment). Each category provides different QoS guarantees for a RCST to satisfy different type of traffic flows (e.g., real time, constant bit rate, etc.). Except for AVBDC, the other four capacity request categories are supported in the current implementation of NCTUns. The following figure shows the popped-up dialog box when one clicks the **Set Capacity** button after choosing a RCST. One has to specify the maximum capacities that a RCST can request for CRA, RBDC, and VBDC traffic flows, respectively. In addition, the valid period in superframe for a RBDC request should be set in this box.

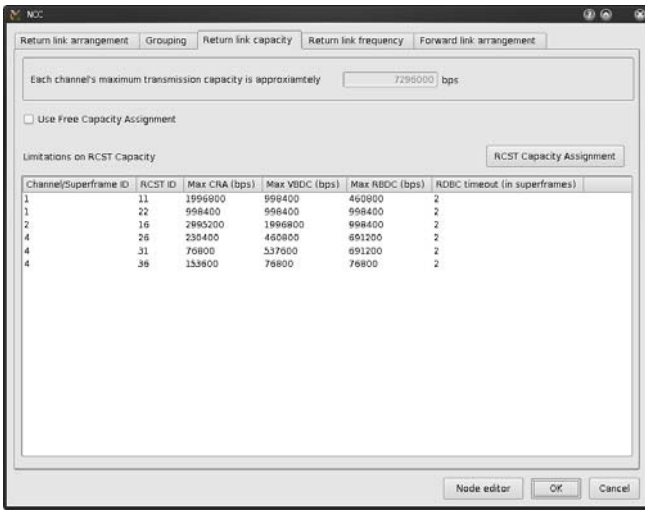


The mechanism of Free Capacity Assignment (FCA) can be enabled by checking the option of **Use Free Capacity Assignment** on the tab of **Return link capacity**. The following figure shows where the option is.



After completing all of the channel capacity assignments, one can examine the final assignment results on the tab of **Return link capacity**. The assignment results will be automatically removed when one changes the parameter values on the tab of **Return link arrangement** because they will affect the maximum transmission capacity of a channel. Also, changing the grouping relationship will remove the existing assignment results. This is because the old assignment may now overbook the channel's maximum transmission capacity. The following figure shows an example of final assignment results.

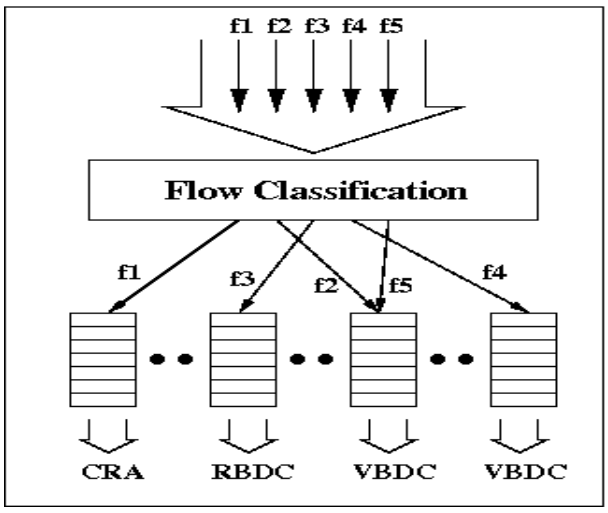
One may see that the final assigned total capacity may differ slightly from the amount that he (she) specified before. This is due to the constraint of the timeslot-based capacity alignment. In fact, the method used by the NCC to grant channel resources to each RCST is timeslot-based. However, in order to let GUI users intuitively deal with channel capacity assignment, the GUI program provides a bit-rate-



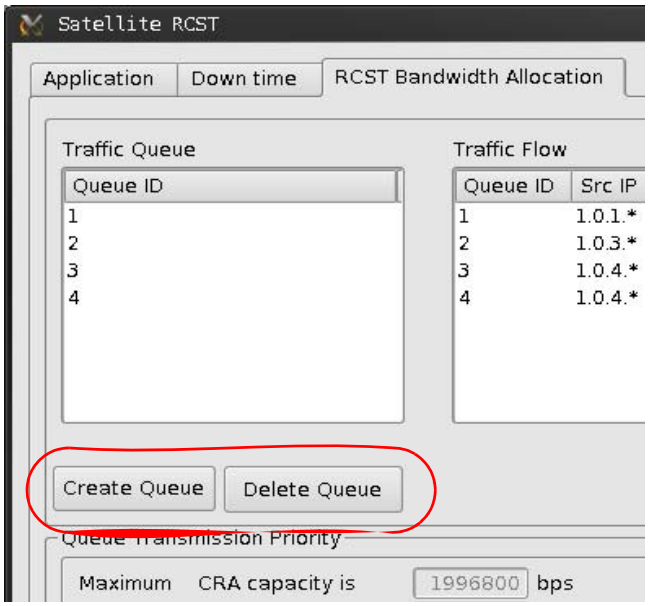
based interface for users to assign channel capacity. If the specified bit-rate-based capacity is not exactly equal to the bit-rate-based value converted from a timeslot-based capacity, the timeslot-based capacity alignment will be applied. This is done for a user (1) not to overbook each channel's maximum capacity and (2) know the actual channel capacity that the NCC will grant to each RCST during simulation.

RCST Bandwidth Allocation

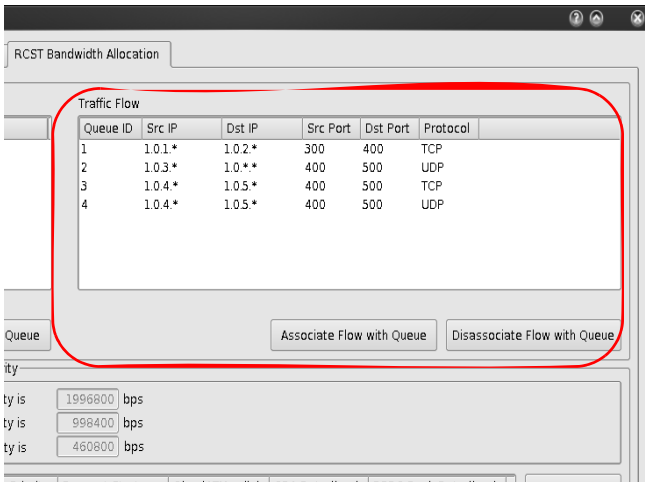
After assigning the return-link channel capacity to each RCST, one has to specify how a RCST uses the allocated channel capacity. The following figure shows how a RCST classifies each flow from its outgoing traffic, how each flow is delivered into a specific output queue, and how the queued data is transmitted out according to a specific capacity request strategy (packet scheduling strategy). As mentioned before, each strategy stands for a specific type of QoS service.



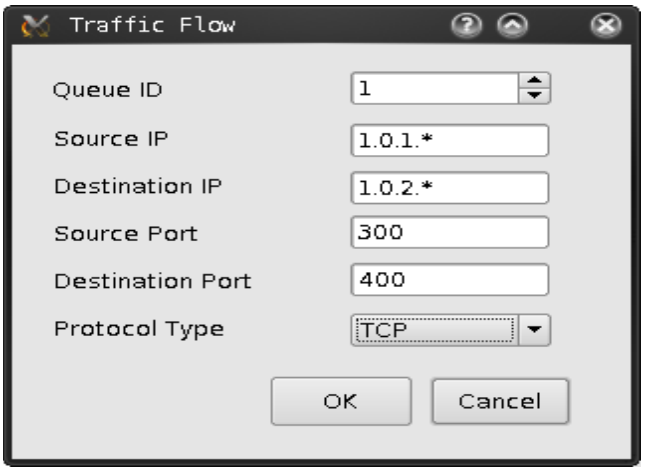
To set up the flow classification rules, one has to first specify how many output queues are used in a given RCST. This is done by clicking the **Create Queue** button and the **Delete Queue** button on the top-left of the tab of **RCST Bandwidth Allocation**. This tab can be popped up by double-clicking a RCST node and its dialog box is shown below.



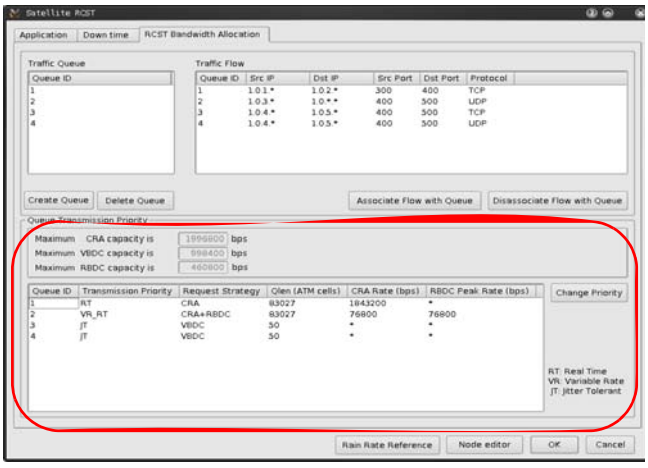
After creating a queue, one can specify what kinds of flows should be delivered into this queue. This can be done by clicking the **Associate Flow with Queue** button and the **Disassociate Flow with Queue** button on the top-right of the tab of **RCST Bandwidth Allocation**. The following figure shows where these two buttons are located.



When clicking the **Associate Flow with Queue** button, one can define a flow and specify to which queue this flow is to be delivered in the popped-up dialog box. The five-tuple flow identifier includes the source IP address, the destination IP address, the source port number, the destination port number, and the protocol. Only TCP and UDP protocols are supported in the current implementation. The following figure shows the dialog box of the traffic flow definition.



After completing the flow definition and the flow-to-queue mapping, one has to specify the capacity request strategy (packet scheduling strategy) applied to each queue. This can be done on the bottom half of the tab of **RCST Bandwidth Allocation**, whose dialog box is shown below.

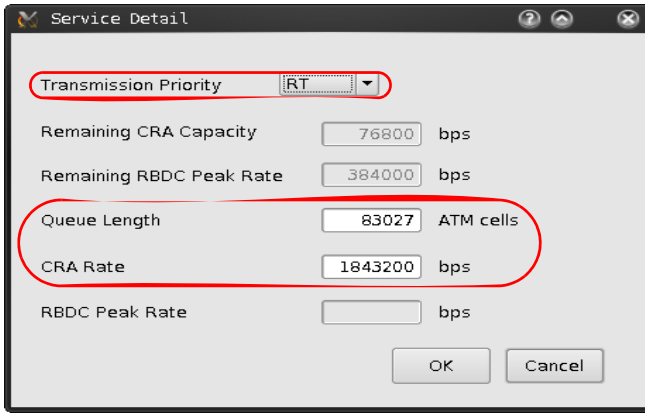


In this area, the maximum CRA capacity, maximum VBDC capacity, and maximum RBDC capacity for each RCST are shown here for the user's reference. They cannot be modified here.

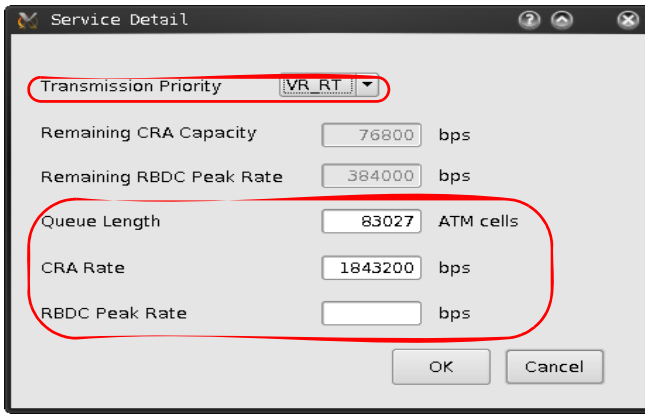
Recall that these maximum capacities were assigned before when the user operated on the tab of **Return link capacity**, which can be popped up by double-clicking the NCC node. After choosing one queue, one can click the **Change Priority** button to set up this queue's capacity request strategy and the parameters related to that request strategy. In the popped-up dialog box, one has to first choose the transmission priority. Four types of transmission priority are

provided: RT (Real Time), VR_RT (Variable Rate and Real Time), VR_JT (Variable Rate and Jitter Tolerant), JT (Jitter Tolerant). Each transmission priority corresponds to a specific request strategy: RT corresponds to CRA, VR_RT corresponds to CRA + RBDC, VR_JT corresponds to RBDC, and JT corresponds to VBDC.

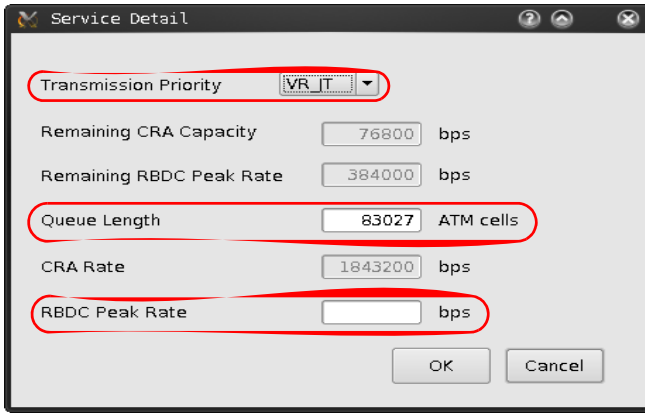
If the transmission priority is set to RT, one has to set the queue length and the CRA rate. The GUI program will disable irrelevant parameters automatically.



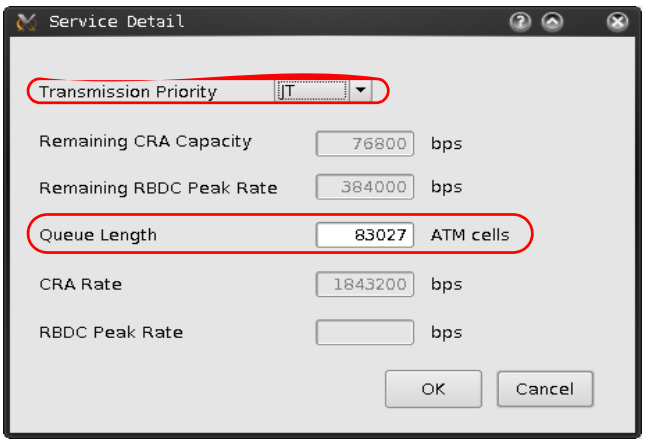
If the transmission priority is set to VR_RT, one has to set the queue length, the CRA rate, and the RBDC Peak Rate.



If the transmission priority is set to VR_JT, one has to set the queue length and RBDC peak rate.



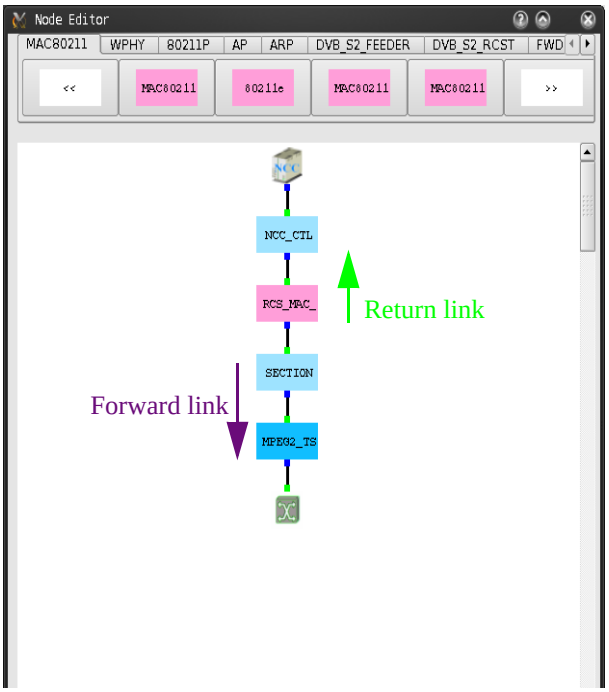
If the transmission priority is set to JT, one only needs to set the queue length.



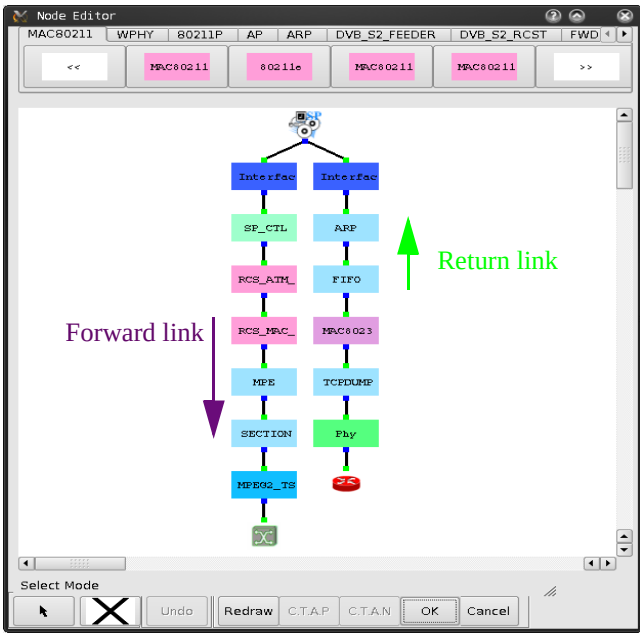
Protocol Stack

In the following, the protocol stack of each RVB-RCS node will be shown. In a protocol stack, some protocol modules are used only for the forward link while some are used only for the return link. In such a special case, their attribute will be clearly shown next to the module icon box. The protocol stack of each DVB-RCS node can be popped up by first double-clicking each node and then clicking the **Node editor** button at the bottom of the popped-up dialog box.

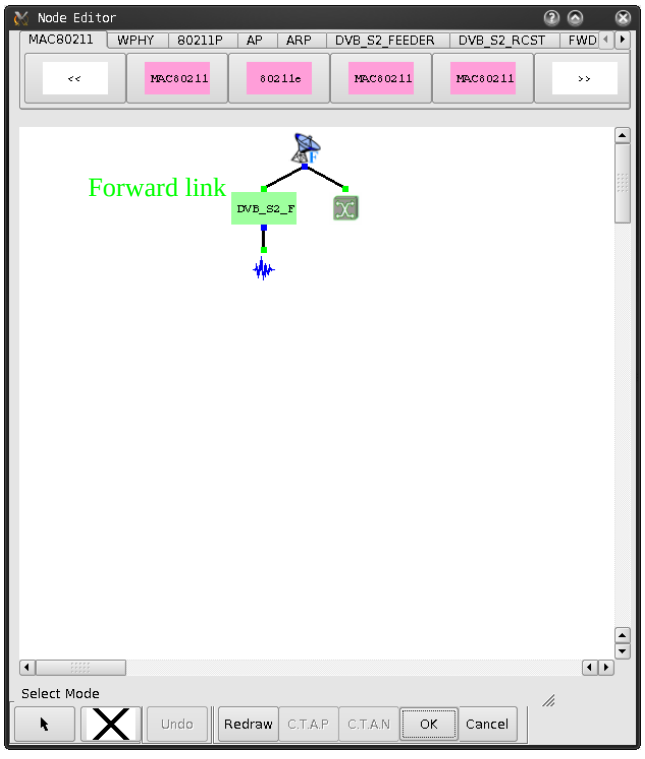
The following figure shows the protocol stack of the NCC node.



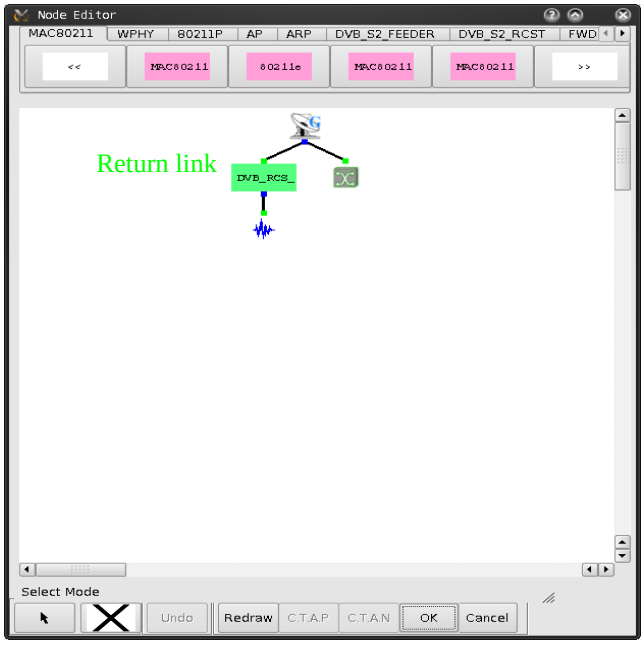
The following figure shows the protocol stack of the SP node.



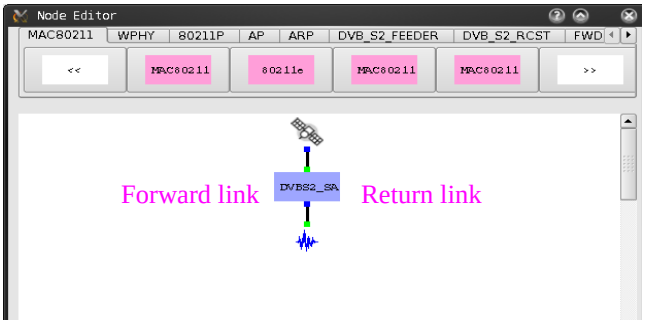
The following figure shows the protocol stack of the Feeder node.



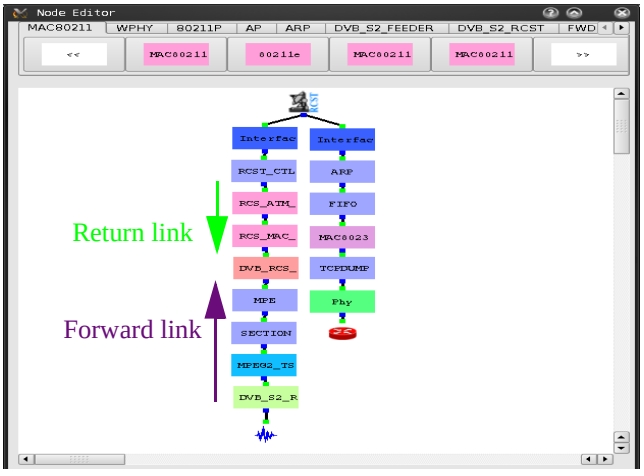
The following figure shows the protocol stack of the TG node.



The following figure shows the protocol stack of the Satellite node.



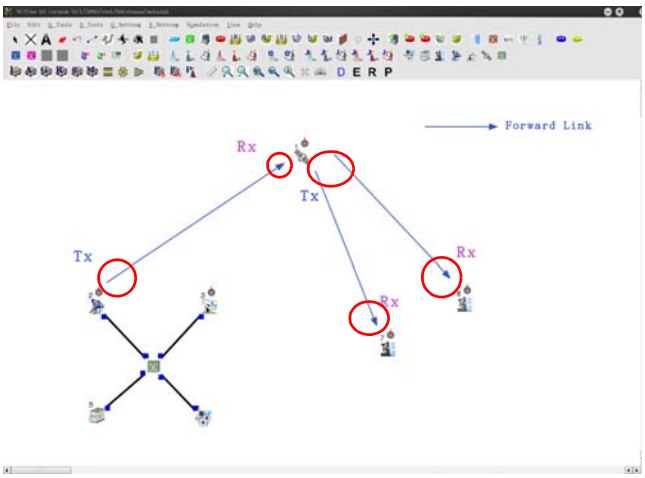
The following figure shows the protocol stack of the RCST node.



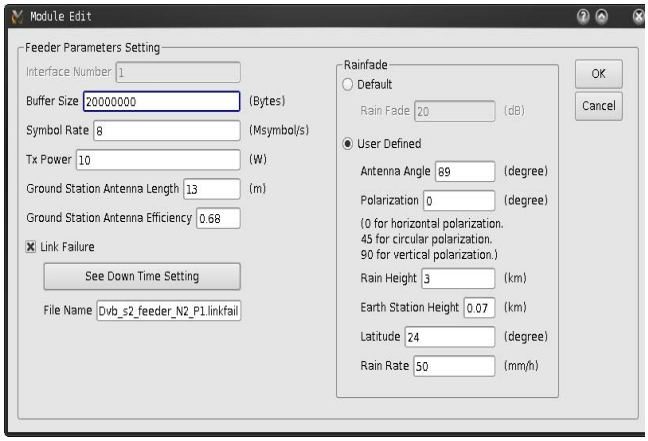
Antenna and Rain Fade Configuration

Regarding the antenna and rain fade configurations, one has to set the related parameters for the forward link and the return link.

The following figure shows where one can set parameters for the forward link. These places include the sending point at the Feeder node, the receiving point at the Satellite node, the sending point at the Satellite node, and the receiving point at a RCST.

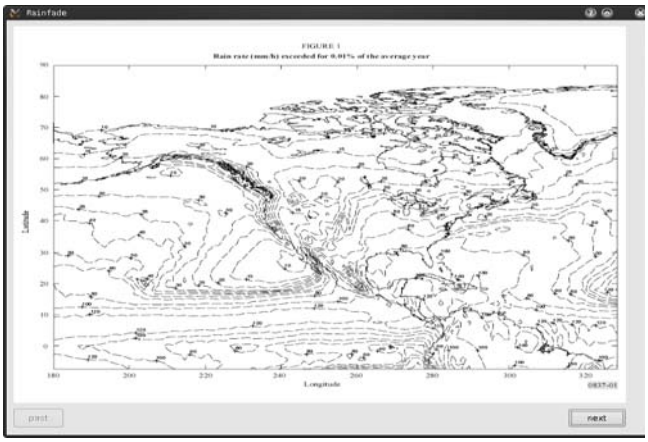


To configure the sending point at the Feeder node, one can pop up the node editor of the Feeder node first. After double-clicking the DVB_S2_FEEDER module box, one will see a popped-up dialog box shown below.

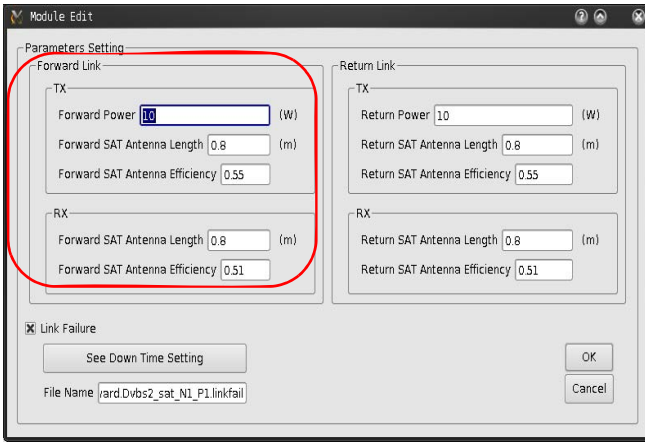


On the left-hand side of this box, one can set up the output buffer size, the symbol rate, and the antenna-related parameters, such as Tx power, ground station antenna length, and ground station antenna efficiency. On the right-hand side of this box, one can set up the rain-fade parameters. One can either set the desired rain fade directly or set the related parameters, such as antenna angle, polarization, rain height, earth station height, latitude, and rain rate, which are used to calculate the rain fade.

When one double-clicks the Feeder node, one can click the **Rain Rate Reference** button at the bottom of the popped-up dialog box to find out the average rain rate at any location on the Earth. The following figure shows the rain rate map.

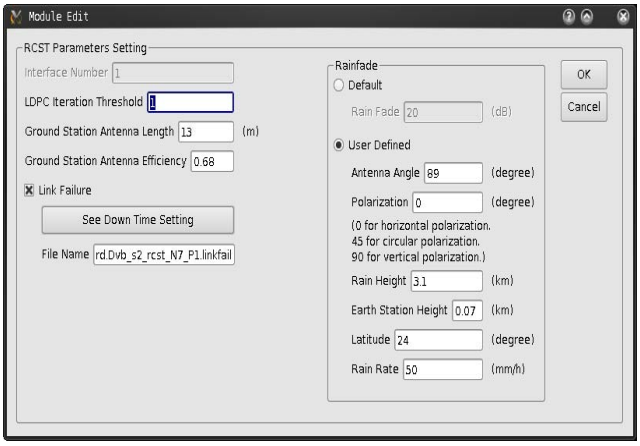


To configure the receiving/sending point at the Satellite node, one can pop up the node editor of the Satellite node first. After double-clicking the DVBS2_SAT module box, one will see a dialog box like what is shown below. On the left-hand side of the box, one can set up the receiving (Rx) antenna-related parameters, such as antenna length and antenna efficiency, and the sending (Tx) antenna-related parameters, such as Tx power, antenna length, and antenna efficiency.

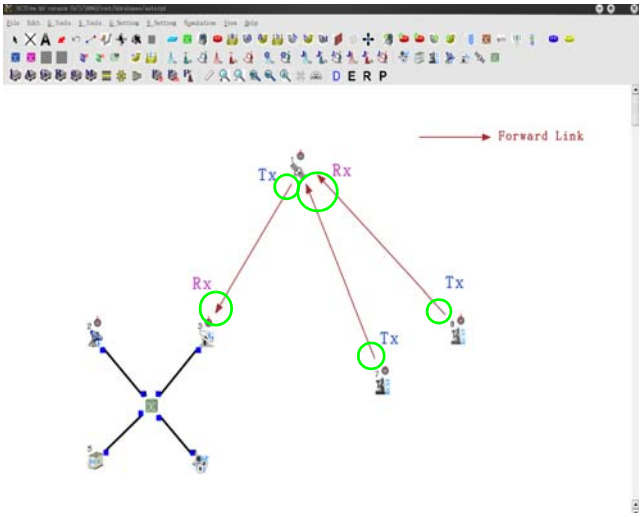


To configure the receiving point at a RCST node, one can pop up the node editor of the RCST node first. After double-clicking the DVB_S2_RCST module box, one will see a dialog box like what is shown below. On the left-hand side of this box, one can set up the LDPC (Low-Density Parity-Check code) iteration threshold and the antenna-related parameters, such as ground station antenna length and ground station antenna efficiency. On the right-hand side of this box, one can set up the rain-fade parameters. One can either set the desired rain fade directly or set the related

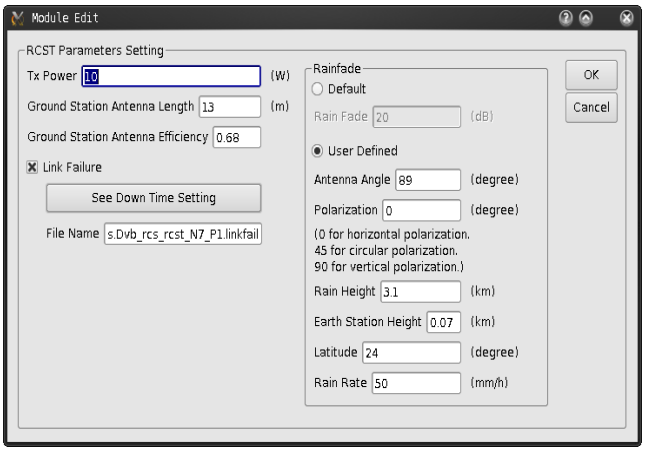
parameters, such as antenna angle, polarization, rain height, earth station height, latitude, and rain rate, which are used to calculate the rain fade.



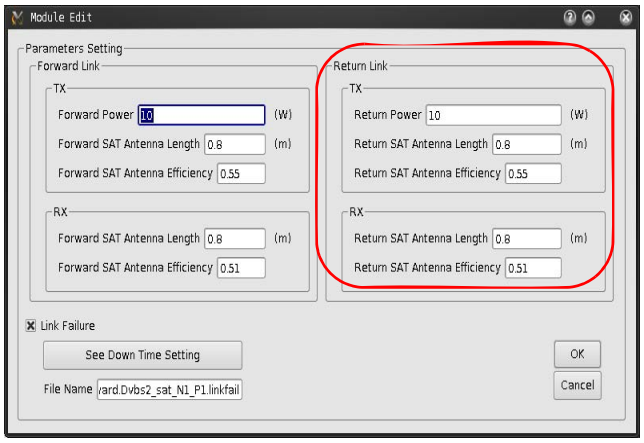
The following figure shows where one can set parameters for the return link. These places include the sending point at a RCST node, the receiving point at the Satellite node, the sending point at the Satellite node, and the receiving point at the TG node.



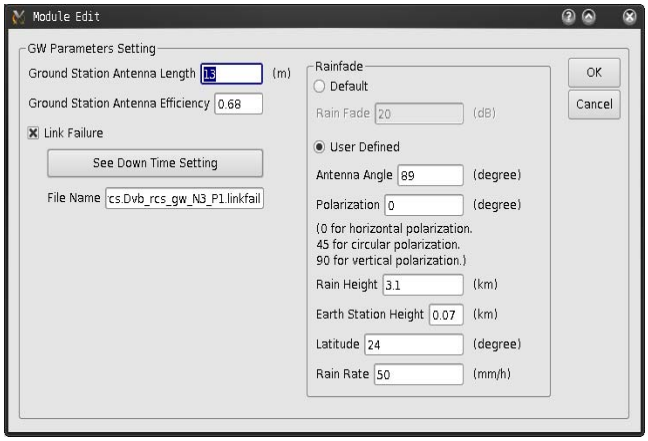
To configure the sending point at a RCST node, one can pop up the node editor of the RCST node first. After double-clicking the DVB_RCS_RCST module box, one will see a popped-up dialog box like what is shown below. On the left-hand side of this box, one can set up the antenna-related parameters, such as Tx power, ground station antenna length, and ground station antenna efficiency. On the right-hand side of this box, one can set up the rain-fade parameters. One can either set the desired rain fade directly or set the relative parameters, such as antenna angle, polarization, rain height, earth station height, latitude, and rain rate, which are used to calculate the rain fade.



To configure the receiving/sending point at the Satellite node, one can pop up the node editor of the Satellite node first. After double-clicking the DVBS2_SAT module box, one will see a dialog box like what is shown below. On the right-hand side of the box, one can set up the receiving (Rx) antenna-related parameters, such as antenna length and antenna efficiency, and the sending (Tx) antenna-related parameters, such as Tx power, antenna length, and antenna efficiency.



To configure the receiving point at the TG node, one can pop up the node editor of the TG node first. After double-clicking the DVB_RCS_GW module box, one will see a dialog box shown below. On the left-hand side of this box, one can set the antenna-related parameters, such as ground station antenna length and ground station antenna efficiency. On the right-hand side of this box, one can set the rain-fade parameters. One can either set the desired rain fade directly or set the related parameters, such as antenna angle, polarization, rain height, earth station height, latitude, and rain rate, which are used to calculate the rain fade.



Summary

In this chapter, we describe the usage of DVB-RCS networks on NCTUns. The content includes the network construction, the channel resource allocation, the RCST QoS packet scheduling, the rain fade effect, etc. One can follow the described steps to set up a DVB-RCS network in the GUI environment.

Reference

[1] ETSI EN 301 790 v1.4.1, “Digital Video Broadcasting (DVB); Interaction channel for satellite distribution systems,” Sept. 2005

19. IEEE 802.11(p) Networks

IEEE 802.11(p) specification is an amendment to the 802.11-2007 standard for improving the performances of CSMA/CA-based networks in vehicular environments. This new specification is also called the WAVE mode, which denotes the **W**ireless **A**ccess in the **V**ehicular **E**nvironment for the 802.11 network family, and standardizes the next-generation Intelligent Transportation System (ITS) network. In this chapter, we first briefly explain the notions of an ITS network and the WAVE-mode operation. We then present how to configure an IEEE 802.11(p) network in NCTUns.

The Concept of an ITS Network

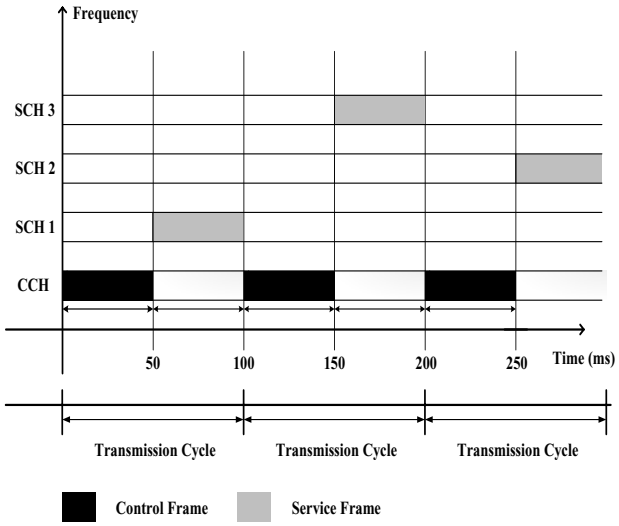
An ITS network is an integrated platform that combines the road network and a communication network. The information related to the road network and vehicle statuses can be distributed over moving vehicles in such a network using radios. Such an integration enables many new applications in the transportation network and the communication network, e.g., improving the safety of vehicles and pedestrians and improving the communication quality among vehicles in a highly-mobile vehicular network.

To satisfy the increasing needs of simulating such ITS networks, NCTUns provides a complete solution to simulate an IEEE 802.11(p) vehicular network. Differing from other solutions, which usually connect the road network simulation and the communication network simulation in a loosely-coupled manner, NCTUns tightly integrates the simulations of a road network and a communication network.

Due to this unique advantage, NCTUns is now a useful tool for the ITS research community. More information about the NCTUns' capabilities on ITS researches can be found in the paper "NCTUns 5.0: A Network Simulator for IEEE 802.11(p) and 1609 Wireless Vehicular Network Researches," which is published in the 2nd IEEE International Symposium on Wireless Vehicular Communications (WiVeC 2008).

The Concept of the WAVE Mode

The WAVE mode defines the operations for the IEEE 802.11-based device in environments where the physical-layer properties are rapidly changing and where very short-duration communications exchanges are required, e.g. a vehicular network. The purpose of this standard is to provide the minimum set of specifications required to ensure interoperability between wireless devices attempting to communicate in potentially rapidly changing communications environments and in situations where message delivery must be completed in time frames much shorter than the minimum in 802.11-based infrastructure or ad-hoc networks [3]. The 802.11(p) specification supports transmission of **Internet Protocol (IP) packets** and **WAVE Short Messages (WSMs)**.



As shown in the above figure, the used frequency spectrum in an 802.11(p) network is divided into one **control channel (CCH)** and several **service channels (SCHs)**. The CCH is dedicated for nodes to exchange network control messages while SCHs are used by nodes to exchange their data packets and WSMs. The link bandwidth of these channels is further divided into transmission cycles on the time axis, each comprising a control frame and a service frame. These frames are represented by the black blocks and the gray blocks, respectively, in the above figure. In the draft standard [5], it is suggested that the duration of a frame (either a control or a service frame) is set to 50 milliseconds. A footnote in the draft standard states that this value may be adjusted in the future standard, showing that different values may be used for different applications. In a transmission cycle, the control frame must be on CCH whereas the service frame can be on a specific SCH.

The 802.11(p) standard divides network nodes into two types: One is **the 802.11(p) on-board unit (OBU)**, which represents a vehicle equipped with a DSRC (**D**edicated **S**hort **R**ange **C**ommunications) radio; the other is **the 802.11(p)**

road-side unit (RSU), which represents a fixed device with a DSRC radio mounted on road sides. The operation of this new network type is briefly explained below.

After attaching to an IEEE 802.11(p)/1609 network, an OBU node should first operate on CCH to gather necessary network information. In the WAVE mode, data packet transmissions are only allowed to occur within a **Wave-mode Basic Service Set (WBSS)**. A node that initiates a WBSS is called a **WBSS provider** and nodes that join a WBSS are called **WBSS users**.

To establish a WBSS, a WBSS provider has to periodically broadcast a **Wave-mode Service Announcement (WSA) Frame** for this WBSS on CCH. A WSA includes the operational information of a WBSS (e.g., the ID of this WBSS and the SCH that this WBSS uses). A node should monitor all WSAs on CCH to know the existence and the operational information of available WBSSs. After knowing the SCH of the WBSS that it wants to join, a node may join this WBSS by periodically switching its channel to the SCH used by this WBSS on its service frames.

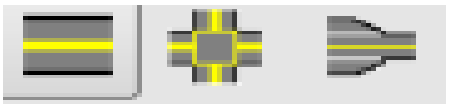
In the WAVE mode, WBSS users need not perform the authentication and association procedures to join a WBSS. (Note: these two procedures are necessary for a node to join an infrastructure BSS in the infrastructure mode of IEEE 802.11(a/b/g) networks.) The reason is that in a high-mobility environment such as a vehicular communication network, wireless link connectivity among vehicles is very fragile. In such a condition, the chance for a high-speed vehicle to join a WBSS is much smaller than a fixed/nomadic computer to join an infrastructure BSS. With this design, a vehicle can quickly utilize the bandwidth of a WBSS after detecting its existence. Because during the lifetime of a WBSS a WBSS provider may change the operational parameters of the WBSS, a WBSS user should switch back to CCH in every transmission cycle to learn the latest information about its WBSS.

In the following, we show the details of how to use NCTUns to construct an 802.11(p) network from the scratch.

Road Network Construction

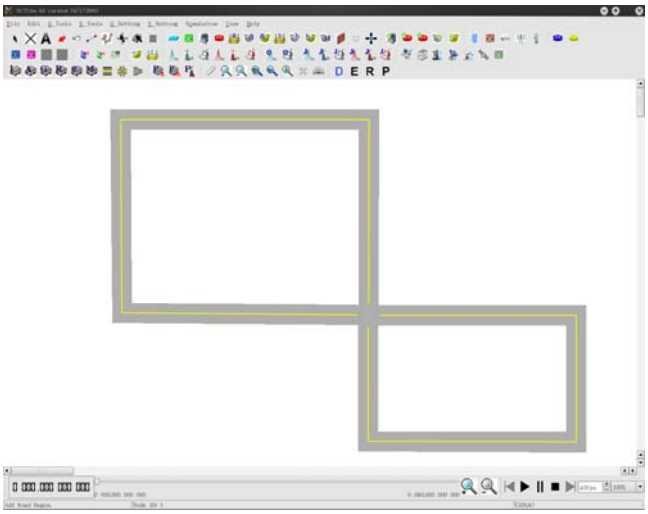
In an ITS network, vehicles are mobile nodes that have communication and networking capabilities and move on the road network only. Such a network model enables many new applications and research opportunities. For example, by exploiting road-condition information shared among moving vehicles and road-side units, each vehicle can move at a proper speed and make turns more safely at intersections to avoid collisions with other vehicles. The first step to conduct an ITS network simulation is constructing a road network. In this section, we explain how to construct a road network in NCTUns.

The following figure shows the three kinds of road objects used to construct a road network, which are listed, from left to right, as follows: **general road segment**, **crossroad**, and **road merger**.



The three different kinds of road objects used to construct a road network in NCTUns

The following figure is an example road network constructed using the provided road objects.

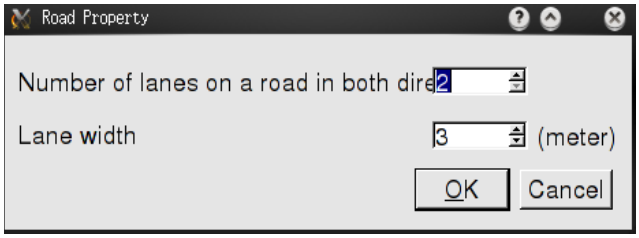


An example road network constructed in the NCTUns GUI environment

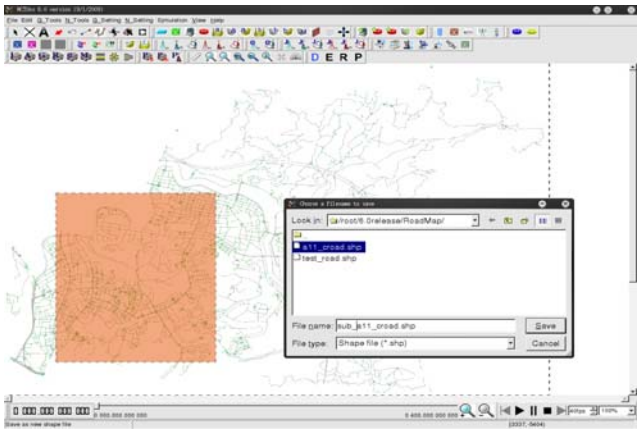
Load Road Map File

NCTUns allows users to import a real-world road map into the GUI program. So far, NCTUns supports road maps in the **shape** format. To import a shape-formatted road map, one can perform the "Load Road Map File (Shape Format) command, which is at "**Menu -> G_Tools -> Load Road Map File (Shape Format)**."

Because the shape-formatted road map represents a road using only lines, before loading a road map one has to determine the number of lanes on a road in both directions and the width of each lane. The dialog box is shown as follows.

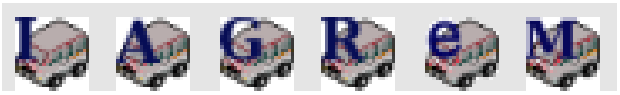


After loading a road map, the GUI program will convert it to the road network structures used by NCTUns. One can use the **"Select an Area to Save As Shape File"** ( ) tool to clip off a smaller road network to suit his (her) own needs. To clip off a road network, one first clicks the icon of this tool, presses the left button of the mouse, and then drag the mouse to draw a colored rectangle area on the working area. After selecting the area to be clipped, one can release the left button of the mouse to end the clipping procedure. A dialog box will be popped up to help the user save the clipped road network.



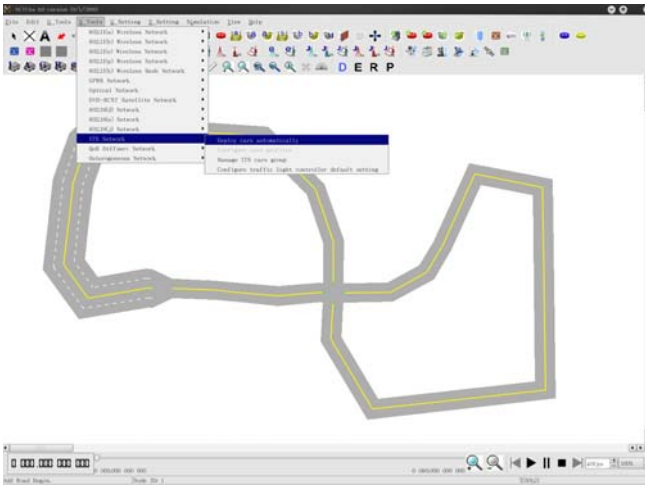
ITS Car Insertion and Placement

Six different types of ITS cars are provided in the current implementation and they are shown (from left to right) in the following figure: **I car** (with an 802.11(b) Infrastructure mode interface), **A car** (with an 802.11(b) ad hoc mode interface), **G car** (with a GPRS radio), **R car** (with a RCST satellite interface), **e car** (with an 802.16(e) mobile wimax interface), and **M car** (with all different types of interfaces). One can deploy ITS cars on a road network one by one. This can be done by first clicking the desired type of ITS car icon on the tool bar and then clicking the desired location for it on the road network. **Note that one must be very careful when placing ITS cars. An ITS car must be placed on the roads (can be any type of road objects); otherwise, the car agent program (which controls the movement of the vehicle that it controls) cannot detect on which road it is moving during simulation! The functions of the car agent program are explained later.**



The six different types of ITS cars supported by NCTUns

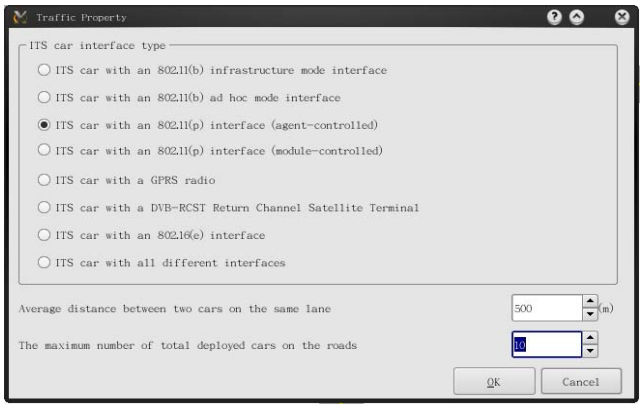
Using the above manual method to deploy a large number of ITS cars will take a user much time and effort. To overcome this problem, NCTUns provides a convenient tool, which can automatically and randomly deploy a large number of ITS cars on the road network for users. The path of this tool is: **Menu -> N_Tools -> ITS Network -> Deploy cars automatically**.



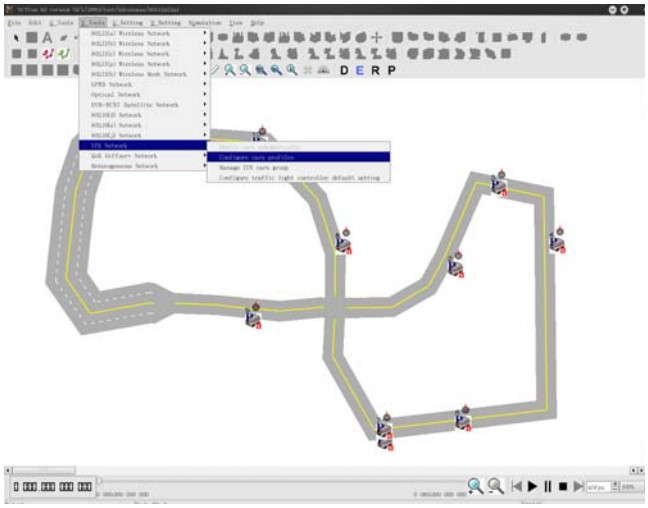
The following figure shows the dialog box of this tool. In this dialog box, one can specify what types of cars should be deployed, the deployment density, and the maximum number of the deployed cars. Note that the actual number of deployed cars may be smaller than the specified maximum number due to the deployment density limitation.

Car Profile Specification

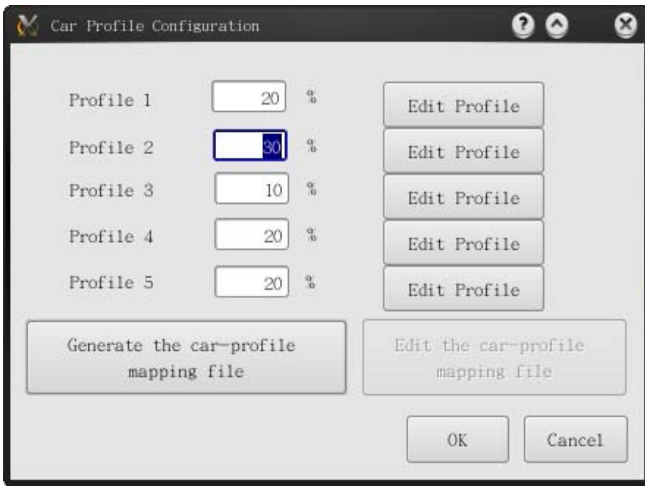
Each ITS car can be specified with different auto-driving behaviors. A driving behavior is defined by a car profile. After inserting ITS cars, one can specify what kind of profile should be applied to an ITS car. This can be done by using



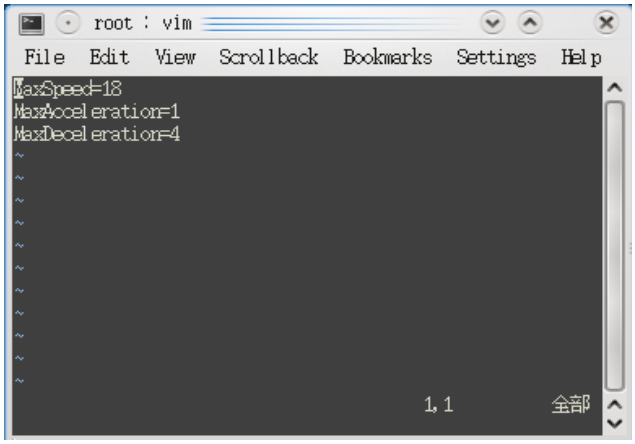
the **Menu -> N_Tools -> ITS Network -> Configure Cars profiles** command in the "**Edit Property**" operating mode. The following figure shows where this command is located.



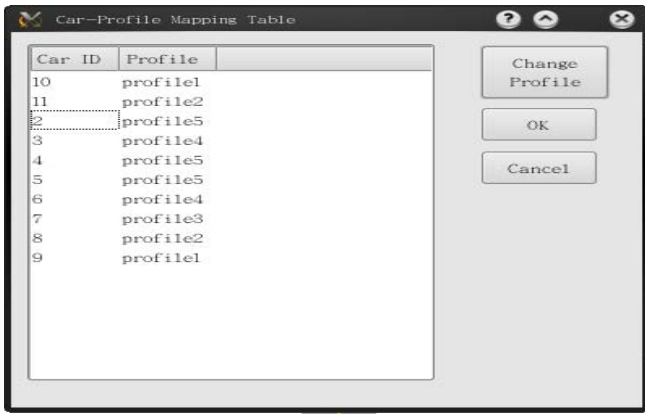
The following figure shows the dialog box used for mapping ITS cars to car profiles. Currently, five profiles are provided for the mapping. One can specify what percentage of ITS cars should use a given profile. After finishing the percentage assignment, one must click the "**Generate the car-profile mapping file"** button to complete the mapping. The GUI program will automatically and randomly assign a profile to each car based on these percentage settings. These assignments are saved to a file, which will be read by all car agents (each of which controls the driving behavior of a car) at the beginning of simulation. Each time when the "**Generate the car-profile mapping file"** button is clicked, the above operation will be performed again. The new assignments may differ from the previous assignments.



When the **"Edit Profile"** button associated with a specific profile is clicked, a vim editor will be executed and the file storing the corresponding profile will be opened by the editor. One can edit the content of the file to change the car profile. A profile contains the characteristic values that a car should follow. For example, the maximum driving speed, the maximum acceleration, the maximum deceleration, etc.



If one wants to change the automatically-generated car-profile mapping, he (she) can click the "**Edit the car-profile mapping file"** button. This function may be desired when the user wants to explicitly specify which car should use which car profile during simulation. The following figure shows the dialog box popped up after clicking the button. In this box, one can first click the desired car to choose it and then click the "**Change Profile"** button to change the profile assigned to the chosen car.



The following figure shows the popped-up dialog box in which the user can change the profile assigned to the chosen ITS car.

Agent Programs

When a crossroad is deployed, a signal agent will be automatically run up when a simulation starts. The signal agent is responsible for changing the states of the traffic light. Similarly, when an ITS car is deployed, a car agent will automatically be run up when a simulation starts. The car agent is responsible for driving the car based on its assigned car profile.

Like a user-level real-life application program, all of these agent programs are user-level programs written in C/C++ and the command strings for launching these programs during simulation should be typed into the "Application" tab of each of these nodes. However, considering that hundreds of ITS cars may need to be automatically deployed on a road network. In such a case, asking the user to open the dialog box of every ITS car to manually type in the command string will be tedious and take much time. For this reason, the GUI program automatically enters a default "CarAgent" command string into the "Application" tab of every deployed ITS car on behalf of users. This command will launch the default car agent program for a simulated ITS car during simulation. If the user wants to use another car agent program with different driving behavior, he (she) can replace the default car agent program with his (her) own one. A user can find and modify the source code of the default car agent program in the NCTUns package to suit his (her) needs. It is in the tools/tacticMANET/lib directory of the NCTUns package.

The default car agent program provided in the NCTUns package represents a proof-of-concept reference implementation showing that such a car agent program can drive a car on a road network with reasonable driving behavior. The user can add more realistic driving behavior and intelligence to the default car agent program. More information about the NCTUns' capabilities on ITS researches can be referred to [1][2].

IEEE 802.11(p) OBU and RSU

As introduced earlier, the IEEE 802.11(p) standard defines a whole-new WAVE operation mode for vehicular networks. Due to the great difference between the 802.11(p) WAVE mode and the traditional 802.11(a)(b)(g) networks, the steps for setting up an 802.11(p) network differ from those for setting up traditional 802.11(a)(b)(g) networks. To clarify these steps, in this section we explain in detail the node types of the IEEE 802.11(p) network supported in NCTUns, demonstrate the dialog boxes of these nodes, and explain the meanings of the parameters shown in their dialog boxes.

Node Types of the IEEE 802.11(p) Network

As shown in the following figure, NCTUns supports IEEE 802.11(p) OBUs and RSUs. The 802.11(p) OBU is further divided into two types based on which component controls its moving behavior (and possibly generates messages). The icon marked with an "a" denotes an agent-controlled 802.11(p) OBU, which means that the moving behavior and message delivery of this OBU are controlled by a real-life car agent program. On the other hand, the icon marked with an "m" denotes a module-controlled 802.11(p) OBU, which means that the moving behavior and message delivery of this OBU are controlled by the "node module" of this OBU in the simulation engine.

The icons of the 802.11(p) OBUs and RSU

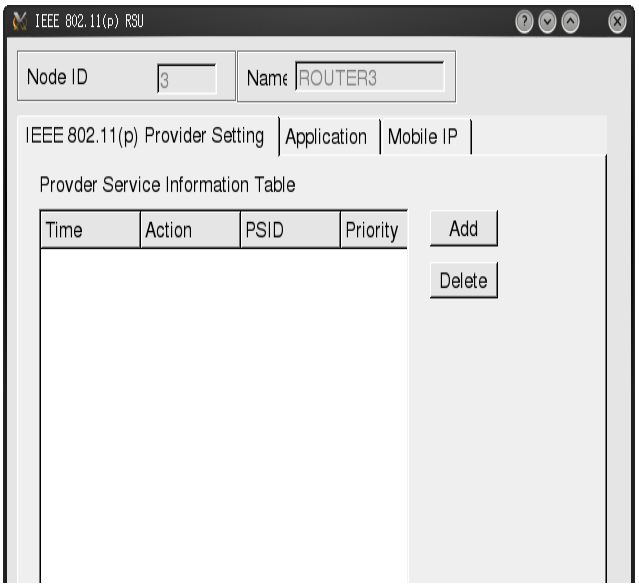
These two OBU types have their respective advantages and disadvantages. An agent-controlled OBU is controlled by an agent program, which is essentially a normal real-life application program. Writing such an agent program is very easy

and is the same as one writes a normal application program on the Linux system. However, the disadvantage with the agent-controlled approach is that each agent program will be run up as an independent process on the Linux system. If thousands of agent programs need to be run up during a simulation, their aggregate resource demands (e.g., CPU cycles, main memory, etc.) may exceed those provided by the system and the simulation speed will be low.

In contrast, a module-controlled OBU is controlled by its own node module in the simulation engine. A module is a C++ class with several member functions. It is compiled and linked with the simulation engine code. To control such an OBU, one need not run up an independent process like one does for an agent-controlled OBU. As a result, even though thousands of OBUs are simulated in a case, one need not run up any process for them. For this reason, a simulation using module-controlled OBUs greatly outperforms that using agent-controlled OBUs on simulation speed and memory consumption. However, to develop a module-controlled OBU, one needs to know how to write/modify an NCTUns module. This is the disadvantage with this approach. Because these two types of OBUs suit different applications, for users' convenience, NCTUns provides both of them for users to best suit their respective needs.

The following figure shows the dialog box of an 802.11(p) RSU, which is composed of three tabs: 1) **IEEE 802.11(p) Provider Setting**, 2) **Application**, and 3) **Mobile IP**.

The Application and Mobile IP settings for an 802.11(p) RSU are the same as those for an 802.11(b) Access Point. To save space, we do not explain them here. One can refer to previous chapters for their usages. In the following, we explain the usage of the **[IEEE 802.11(p) Provider Setting]** tab in detail.

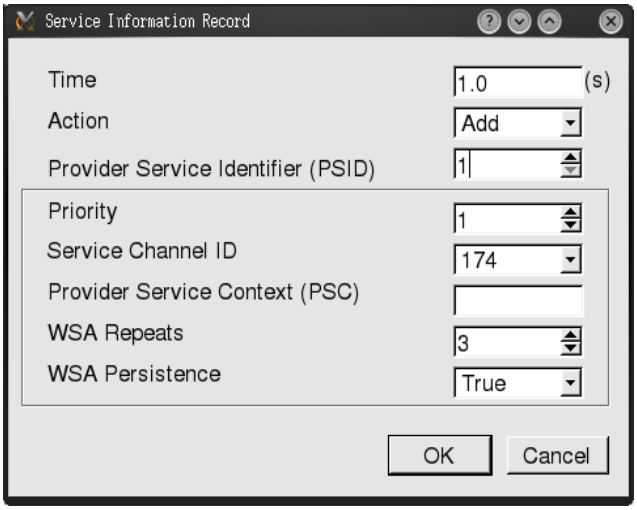


Under the **[IEEE 802.11(p) Provider Setting] tab,** one can specify which services a RSU node intends to provide during simulation. (A service in an 802.11(p) network is defined as broadcasting of messages for some specific objective, e.g., road condition notification.) Clicking the "Add" button will pop up a dialog box for adding/deleting an entry into/from the provider service information table. As shown in following figure, a service information entry is composed of eight fields. **1) Time, 2) Action, 3) Provider Service Identifier (PSID), 4) Priority, 5) Service Channel ID, 6) Provider Service Context (PSC), 7) WSA Repeats, and 8) WSA Persistence**.

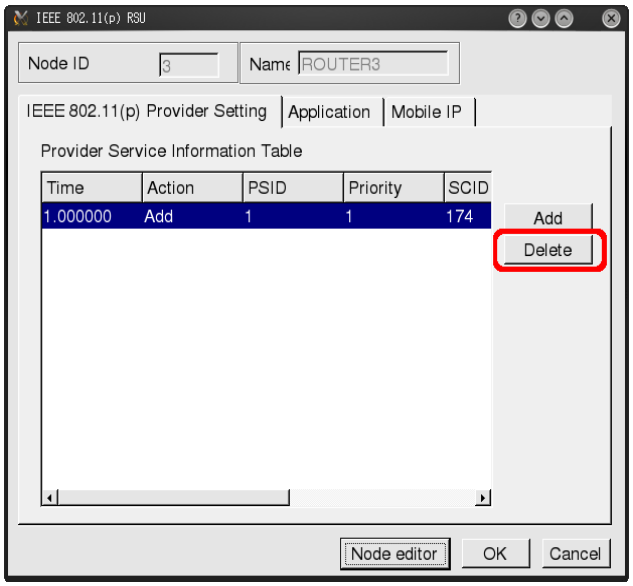
The **Time** field indicates when this service information entry will be processed by this 802.11(p) provider node during simulation; the **Action** field specifies which action should be taken by this provider when the simulation clock advances to the time specifed in the "time" field. NCTUns now supports two actions: **add** a service and **delete** a service; the **PSID** field denotes the numerical identifier of this service.

The **Priority** field specifies the priority level of this service. A higher value of this attribute means that the service has a higher priority for OBUs to receive. For example, when several services that an OBU ***x*** has subscribed to are broadcasting their messages on the control channel, the OBU ***x*** should listen to the messages broadcast by the service with the highest priority level.

The "**Service Channel ID**" field specifies the ID of the service channel that this service uses. The allowed service channel IDs are 174, 175, 176, 180, 181, and 182. The **PSC** field denotes the name of this service, which can be any arbitrary ASCII string. The **WSA Repeats** field denotes the number of WSAs that should be repeatedly sent within a control frame. To be precise, the (WSA Repeats + 1) is the number of WSA occurrences within a control frame. (Note: WSA is an action frame with capability information elements and contains additional fields that describe the provider information needed by the potential service users. WSAs are sent by its service provider on the CCH. Finally, the **WSA Persistence** field indicates whether the provider will periodically transmit WSAs on each CCH frame. If this value is set to "True," the provider will transmit **(WSA_REPEATS + 1)** WSAs on every CCH frame. Otherwise, it only transmits **(WSA_REPEATS + 1)** WSAs on the first CCH frame when forming a WBSS.



One can delete a service information entry by clicking the "Delete" button. The following is an example to delete a service information entry.

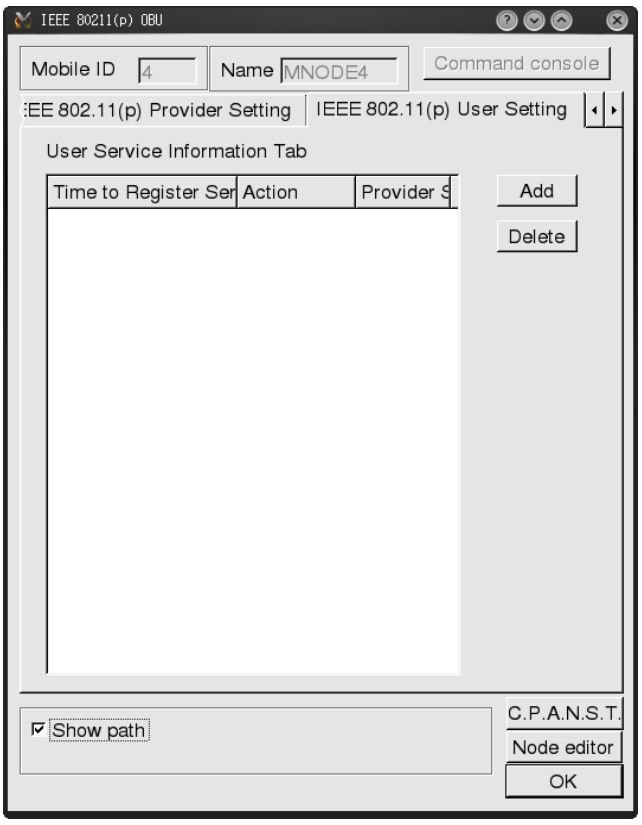


The functions of the **Application and Mobile IP** tabs of an 802.11(p) RSU are the same as those of an 802.11(b) infra-structure mode mobile node. To save space, we do not explain them here. One can refer to previous chapters for their usages.

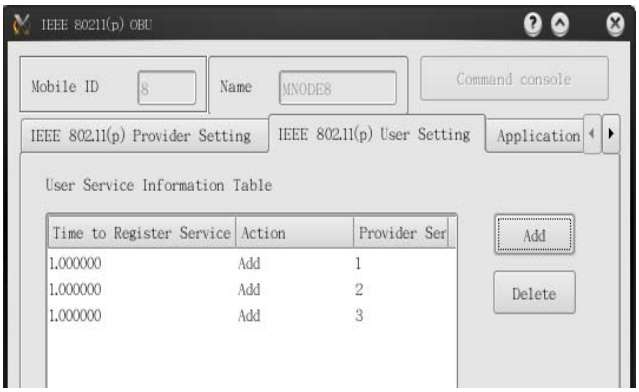
The dialog box for setting the attributes of an IEEE 802.11(p) OBU is shown in the following figure, which comprises six tabs: 1) **IEEE 802.11(p) Provider Setting,** 2) **IEEE 802.11(p) User Setting,** 3) **Application,** 4) P**ath (for Testing),** 5) **Down Time,** and 6) **Mobile IP**.

In an 802.11(p) network, an OBU is allowed to provide services for other OBUs and subscribe to services provided by other OBUs or RSUs. To provide services for other OBUs, one can specify the **[IEEE 802.11(p) Provider Setting]** tab. Because the functions of the **[IEEE 802.11(p) Provider Setting]** tab is the same as those in the dialog box of an 802.11(p) RSU, we do not explain them again here.

Under **the [IEEE 802.11(p) User Setting] tab**, one can specify when and to which service provider (by specifying the ID of the service) an 802.11(p) OBU intends to subscribe during simulation. Clicking the "Add" button will pop up the dialog box for adding/deleting a service information entry, which is shown in the following figure. As one sees, this dialog box contains three fields. The first field is the "Time to Register Service" field, which denotes when this OBU intends to subscribe to this service. The second field is the "Action" field, which denotes the action that this OBU intends to do on this service on the given time. Two actions are now supported: **Add** a service (to the subscription table) and **Delete** a service (from the subscription table). The last field is the "Provider Service Identifier (PSI)" field, which denotes the numerical identifier of the chosen service.



The following figure shows an example user setting for an 802.11(p) OBU node. In this example, the OBU subscribes to three services with IDs 1, 2, and 3, at the first second of the simulated time. If the OBU receives WSAs of the services 1, 2, and 3 after the 1st second of the simulated time, its **Wave Management Entity (WME)** module will trigger its internal procedure to attach to the WBSSs of these three services for receiving their broadcast messages.



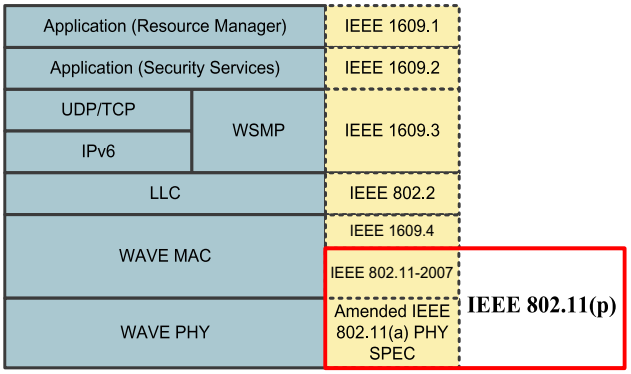
The functions of the **Application, Path, Down Time, Mobile IP** tabs of an 802.11(p) OBU are the same as those of an 802.11(b) infrastructure mode mobile node. To save space, we do not explain them here. One can refer to previous chapters for their usages.

Note that it is not recommended to specify the moving path of an ITS car using the functions on the **Path** tab because if the ITS car specifies a **Car Agent** program to dynamically control its moving path, these two moving-control mechanisms will interfere with each other, resulting in unexpected simulation results. For this reason, these two moving-control mechanisms should not be used simultaneously.

Setting for WSM Transmission

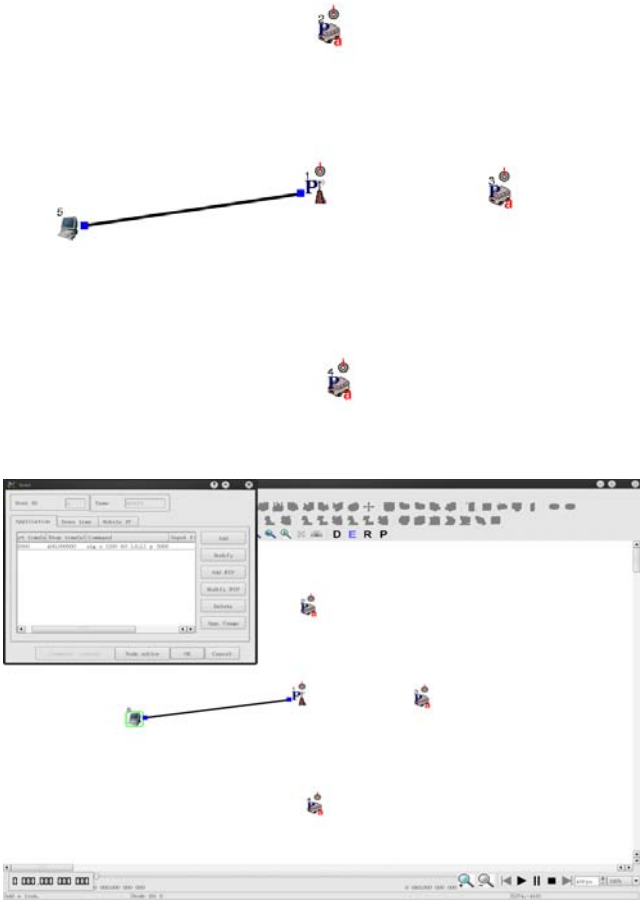
The following figure shows the protocol stack of an IEEE 802.11(p)/1609 network. As one sees, the IEEE 1609.3 specification defines the Wave Short Message Protocol (WSMP), which is a layer-3 and layer-4 protocol to regulate transmission and reception of WSMs. Due to the unique architecture of NCTUns, the most direct way to support WSMP would be to implement it in the Linux kernel. However, this way NCTUns will need to modify the current Linux kernel network subsystem and socket APIs to a great extent, which greatly increases the complexity and efforts for maintaining the WSMP implementation in the kernel.

To solve this problem, NCTUns realizes WSMP by using user-level C/C++ program APIs. To enable WSM transmission, one only needs to run up two programs **WSM** and **WSM_Forwarding** in a simulation. These two programs have been included in the NCTUns package and will be automatically installed in the /usr/local/nctuns/tools directory. Their source codes are available in the $package/tools/tactic_api/lib/ directory, where $package denotes the directory where the NCTUns package is installed. One can easily modify these two programs to meet his/her own needs.

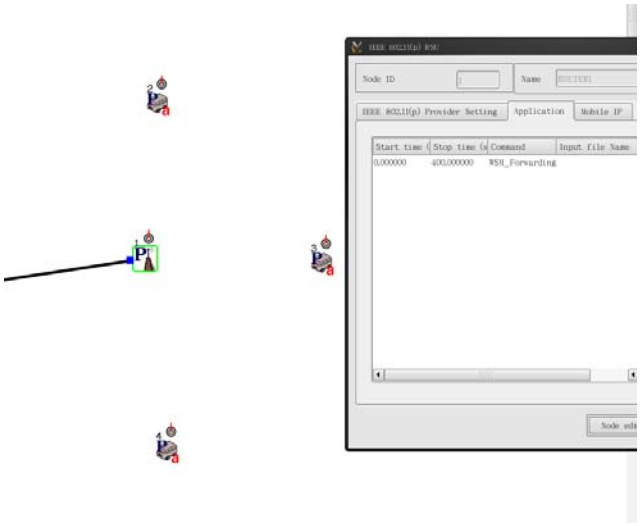


In the following, we demonstrate the steps required to enable WSM transmission in an 802.11(p) network. The following figure shows the network topology of this example case, which is composed of three 802.11(p) OBUs, an 802.11(p) RSU, and a host on the Internet.

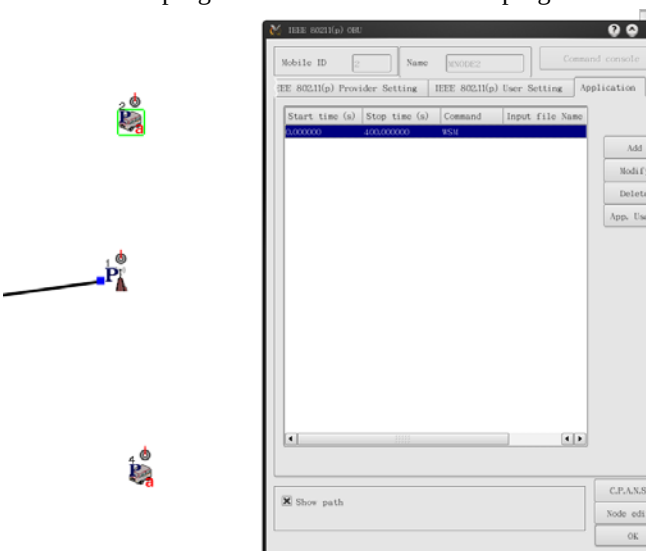
In this example case, the host wants to transmit greedy UDP packets to node 2 (the 802.11(p) OBU on the top) using WSMP. The following figure shows the setting of the host node for transmitting greedy UDP traffic to node 2 (with the IP 1.0.2.1).



To make the RSU capable of forwarding data packets using WSMP, one should run the **WSMP_Forwarding** program via its **Application** tab on the RSU node. The following is an example.



Finally, as shown in the following figure, one should run the **WSM** program on OBUs that want to transmit/receive WSM messages. The encapsulation and decapsulation of WSMs are realized as program functions in the WSM programs.



Summary

In this chapter, we describe how to use NCTUns to build wireless vehicular networks, e.g., 802.11(p) networks, to conduct ITS researches. The detailed operations for road network construction, ITS cars insertion, and car profile mapping and editing are presented.

Reference

[1] S.Y. Wang and C.C. Lin, "NCTUns 5.0: A Network Simulator for IEEE 802.11(p) and 1609 Wireless Vehicular Network Researches," the 2nd IEEE International Symposium on Wireless Vehicular Communications (WiVeC 2008).

[2] S.Y. Wang, C.L. Chou, Y.H. Chiu, Y.S. Tseng, M.S. Hsu, Y.W. Cheng, W.L. Liu, and T.W. Ho, "NCTUns 4.0: An Integrated Simulation Platform for Vehicular Traffic, Communication, and Network Researches," 1st IEEE International Symposium on Wireless Vehicular Communications, September 30 - October 1, 2007, Baltimore, MD, USA.

[3] "IEEE 802.11p/D3.0," IEEE Standards Activities Department, July 2007.

[4] IEEE Std 802.11-2007 (Revision of IEEE Std 802.11-1999), June 12, 2007.

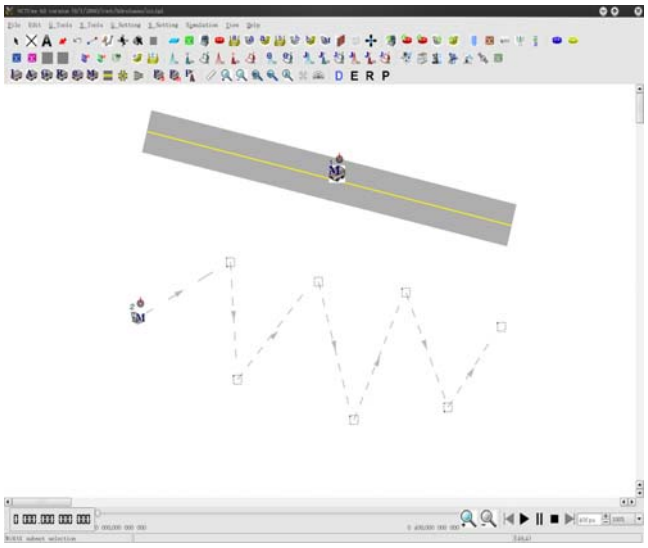
[5] "IEEE 1609.4 Trial-Use Standard for Wireless Accesses in Vehicular Environments (WAVE) - Multi-channel Operation" IEEE Vehicular Technology Society, October 2006.

20. Multi-interface Mobile Nodes

As the IC technology advances, nowadays many consumer electronic devices are equipped with multiple heterogeneous wireless interfaces. Such devices have enabled new research topics including heterogeneous network handover and wireless trunking. For this research trend, NCTUns supports multi-interface mobile nodes, which are mobile nodes each equipped with multiple heterogeneous wireless interfaces.

The Multi-interface Mobile Node Concept

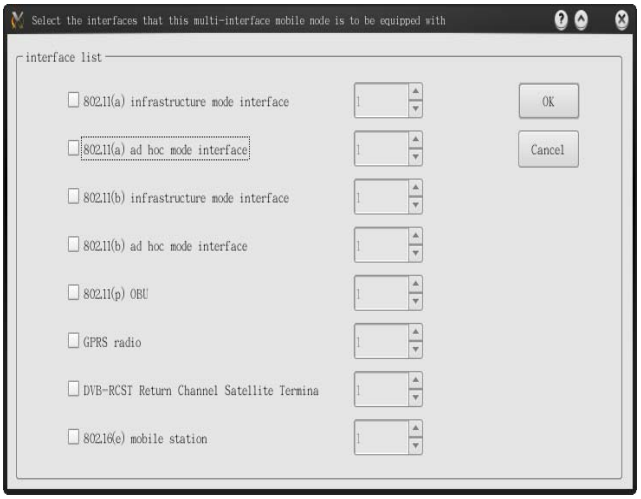
A multi-interface mobile node is a mobile node equipped with multiple different wireless interfaces. Currently, a multi-interface mobile node is equipped with eight different kinds of wireless interfaces: an 802.11(a) infrastructure mode interface, an 802.11(a) ad hoc mode interface, an 802.11(b) infrastructure mode interface, an 802.11(b) ad hoc mode interface, an 802.11(p) interface, a GPRS interface, a DVB-RCST satellite interface, and an 802.16(e) interface. There are two types of multi-interface mobile nodes: (1) multi-interface mobile node ( ) and (2) multi-interface ITS car ( ). As shown in the following figure, a multi-interface mobile node is allowed to move in any pattern in the field (like a WLAN mobile node moving in the random waypoint fashion). However, a multi-interface ITS car is only allowed to move on a road network.



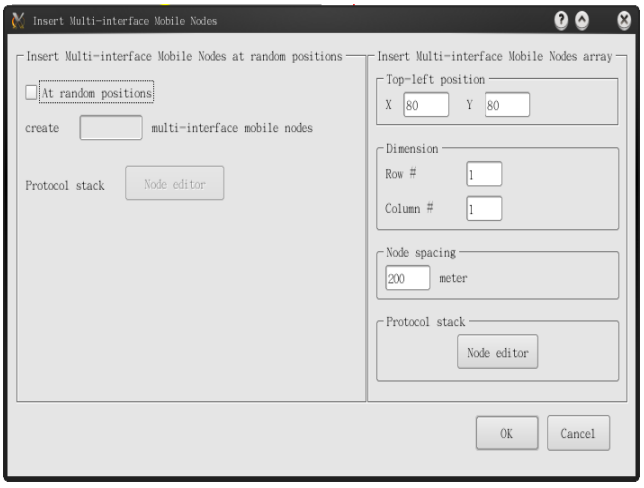
Setting Multi-interface Mobile Nodes

Insert Multi-interface Mobile Nodes

One can select the icon of the multi-interface mobile node ( ) and then left-click the mouse in the field to add a multi-interface mobile node. After one left-clicks the mouse, the following dialog box will be popped up for users to specify which type of and how many radio interfaces to be added into this multi-interface node. As introduced earlier, NCTUns now supports eight different types of wireless mobile interfaces that can be added into a multi-interface node.

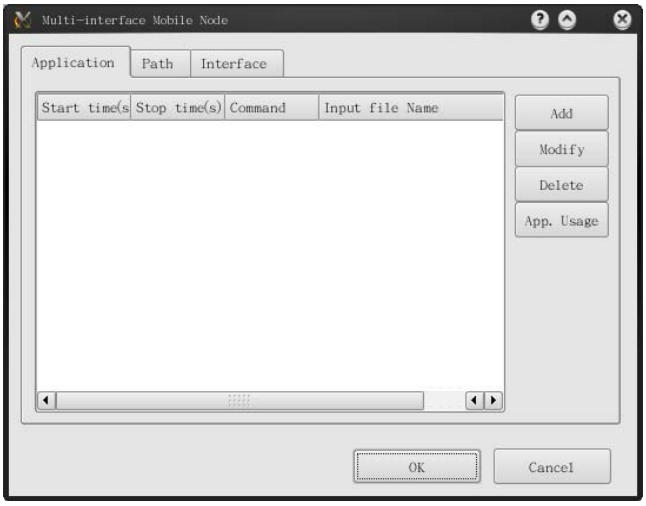


An alternative is to use the automatic deployment tool to add a number of multi-interface mobile nodes at a time. The location of the automatic deployment tool for multi-interface mobile nodes is **Menu -> N_Tools -> Heterogeneous Network -> Insert multi-interface Nodes**. The following figure shows the dialog box of this deployment tool.

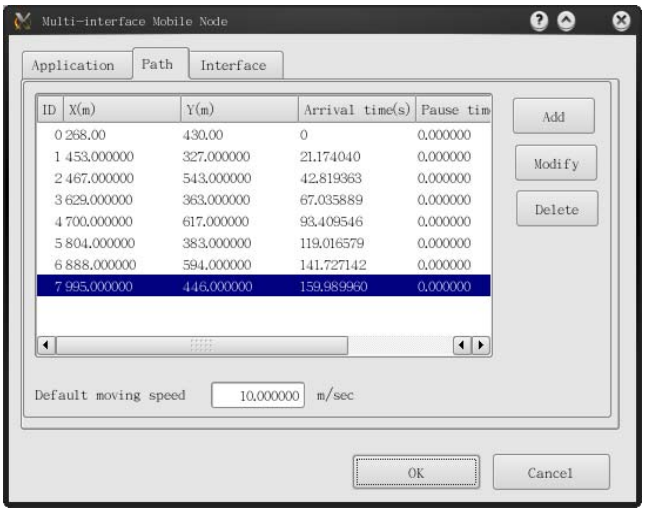


Specify Multi-interface Mobile Nodes

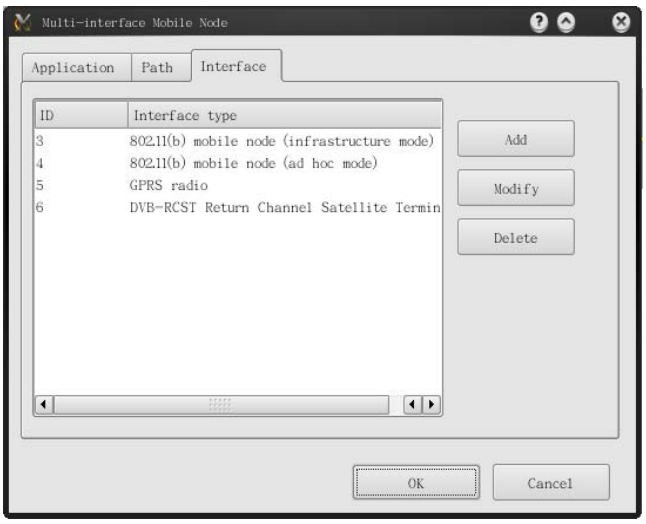
In the following, we show how to set up a multi-interface mobile node. The dialog box of a multi-interface mobile node will be popped up after one double-clicks a multi-interface mobile node icon. Under the **Application** tab, one can specify the application programs that will be executed on this multi-interface mobile node during simulation.



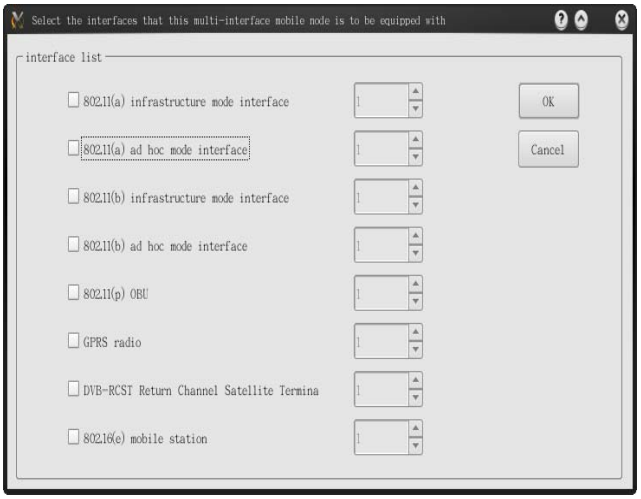
Under the "**Path**" tab, one can specify the moving path of this multi-interface mobile node. The following figure shows an example path setting. Another method to specify the moving path is to use the mouse to click-drag-click... to graphically specify the moving path in the working area. This operation is exactly the same as that for specifying the moving path for a single-interface mobile node.



Under the **Interface** tab, one can add/remove/change the radio interfaces equipped on this multi-interface node. The following figure shows an example interface setting for a multi-interface mobile node.

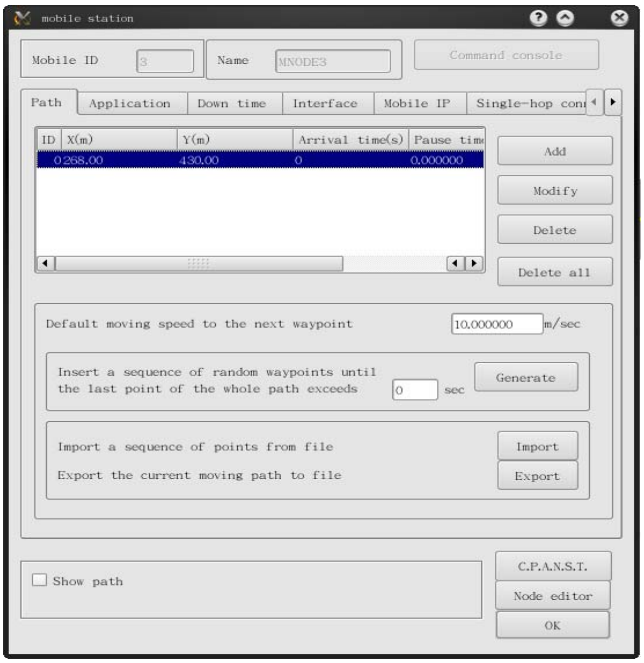


As shown in the following figure, by clicking the "**Add**" button, one can select which type of and how many radio interfaces to be added into this multi-interface node. As introduced earlier, NCTUns now supports eight different types of wireless mobile interfaces that can be added into a multi-interface node.



One also can press the "**Modify**" button to set up the properties of a specific radio interface. Before clicking the "**Modify**" button, one has to choose one of the entries listed in the interface table to specify which interface he/she intends to modify. If one clicks the "**Modify**" button directly without specifying an interface entry, by default the nctun-

sclient will invoke the dialog box of the first interface. The following figure shows an example dialog box after one clicks the "**Modify**" button.

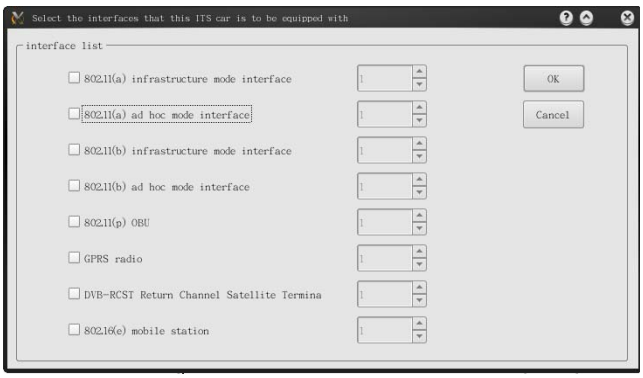


Setting Multi-interface ITS Cars

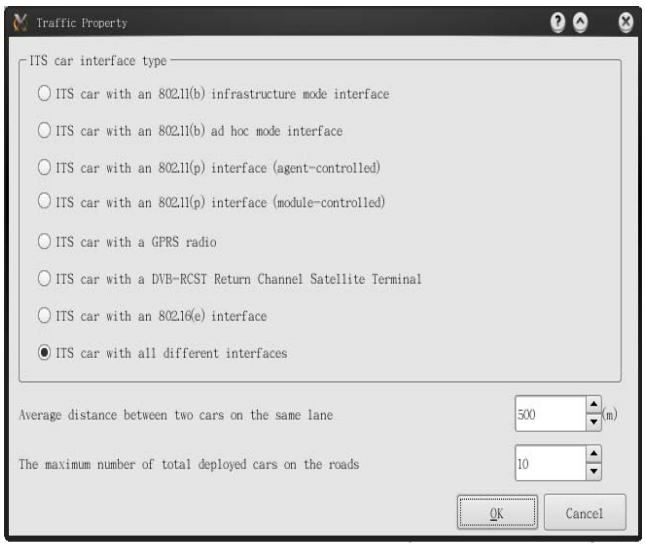
Insert Multi-interface ITS Cars

One can select the icon of the multi-interface car ( ) and then left-click the mouse in the field to add a multi-interface mobile node. After one left-clicks the mouse, the following dialog box will be popped up for users to specify which type of and how many radio interfaces to be added into this multi-interface car. As introduced earlier, NCTUns now supports eight different types of wireless mobile interfaces that can be added into a multi-interface car.

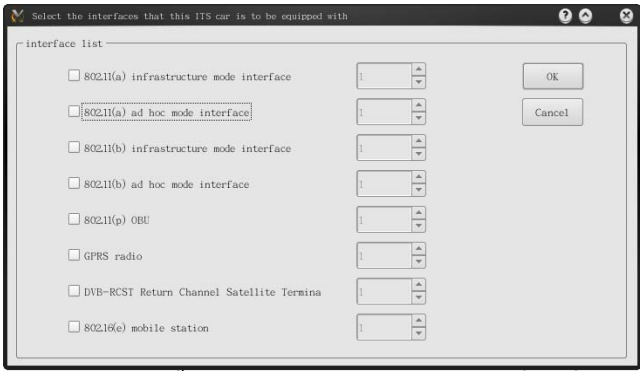
.



An alternative is to use the automatic deployment tool to add a number of multi-interface ITS cars at a time. The location of the automatic deployment tool for multi-interface ITS cars is **Menu -> N_Tools -> ITS Network -> Deploy cars automatically** and select the session of "**ITS car with all different interface**"**.** The following figure shows the dialog box of this deployment tool.



After setting up the "**Average distance between two cars on the same lines**" and "**The maximum number of total deployed car on the road**," the dialog box for specifying the interfaces of an ITS car will be popped up. One can specify which types of and how many radio interfaces that he/she intends to add into the deployed ITS cars. (Note that the actual number of deployed cars may be smaller than the specified maximum number due to the deployment density limitation.)

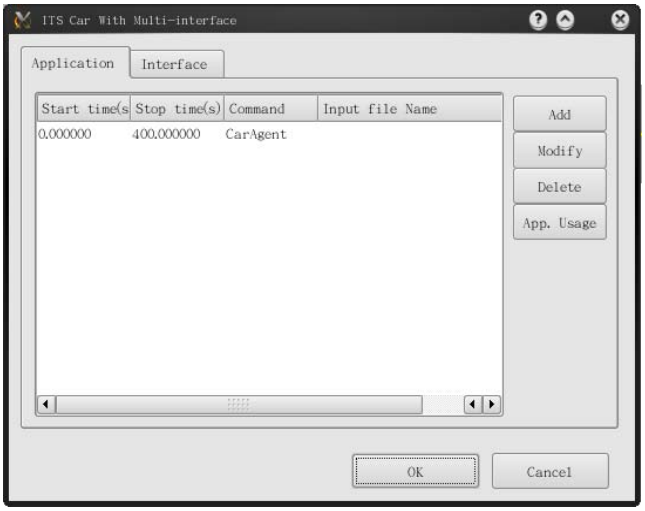


Specify Multi-interface ITS Cars

In the following, we show how to set up an ITS car. One can invoke the dialog box of an ITS car by double-clicking its icon in the field. Similar to that of a multi-interface mobile

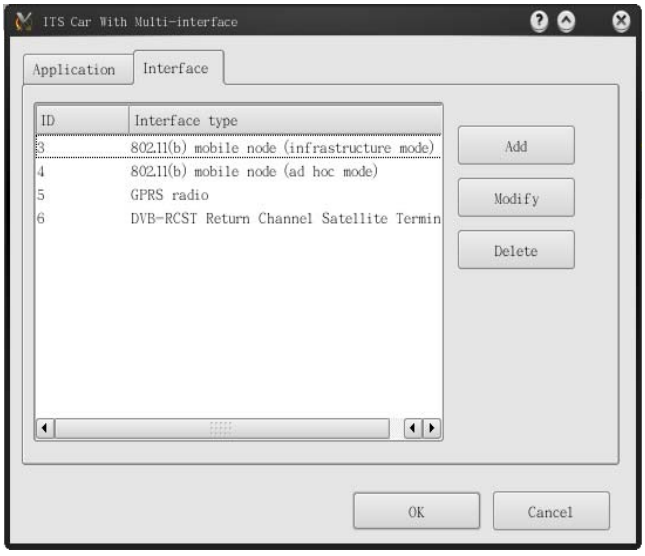
node, the dialog box of an ITS car comprises two tabs: **Application** and **Interface**. The functions on these tabs for an ITS car are similar to those for a multi-interface mobile node. In the section, we only highlight the notable settings for an ITS car.

As shown as follows, for each ITS car, the GUI automatically enters a fixed command "**Car Agent**" into the "**Application**" tab, which will launch the default car agent program during simulation. The **Car Agent** program is responsible for simulating the behavior of a driver, e.g., driving the car in line with the road direction, keeping an appropriate distance between neighboring cars, keeping the driving speed within a specified range, making turning decisions at intersections, etc. If one wants simulated cars to behave in a different manner, he/she can replace the default car agent program with his/her own. One can find and modify the source codes of the default car agent program in the NCTUns package to suit his/her needs. The locations of the source codes are in the **tools/tacticMANET/lib** directory of the NCTUns package.

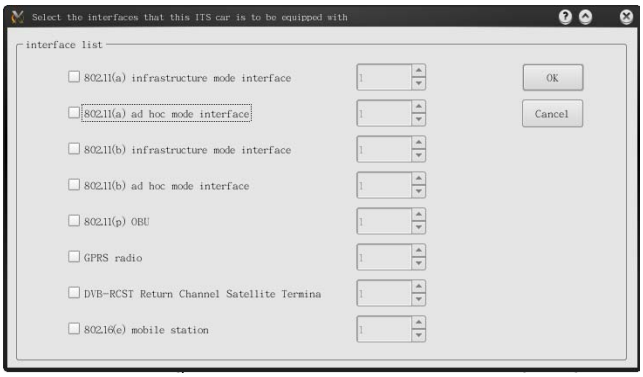


NCTUns does not allow a user to manually specify the moving path of an ITS car because, if an ITS car specifies a **Car Agent** program to run on it, the **Car Agent** program will control the moving of the car during simulation. In case another moving path were also specified, the two moving-control mechanisms would interfere with each other, resulting in unexpected simulation results. For this reason, NCTUns removes the movement-specifying functions for an ITS car.

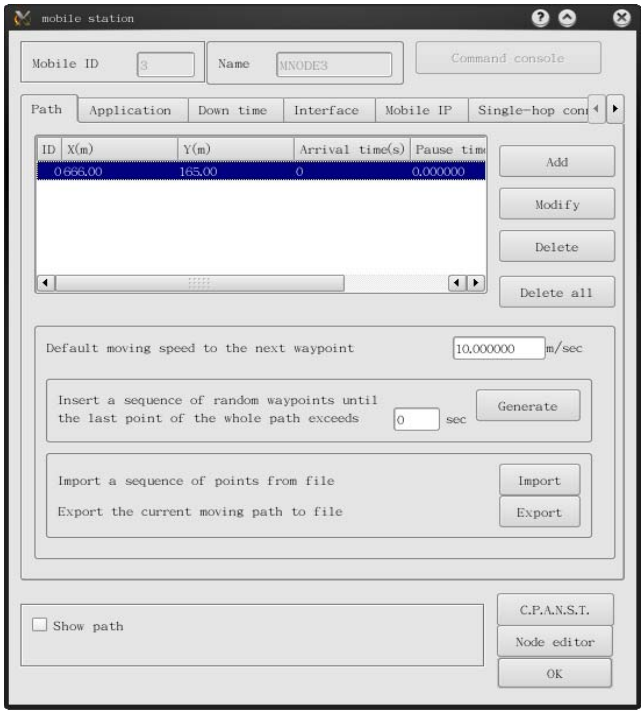
Under the **Interface** tab, one can add/remove/change the radio interfaces equipped on this ITS car. The following figure shows an example interface setting for an ITS car.



As shown in the following figure, by clicking the "**Add**" button, one can select which type of and how many radio interfaces to be added into this ITS car. As introduced earlier, NCTUns now supports eight different types of wireless mobile interfaces that can be added into an ITS car.

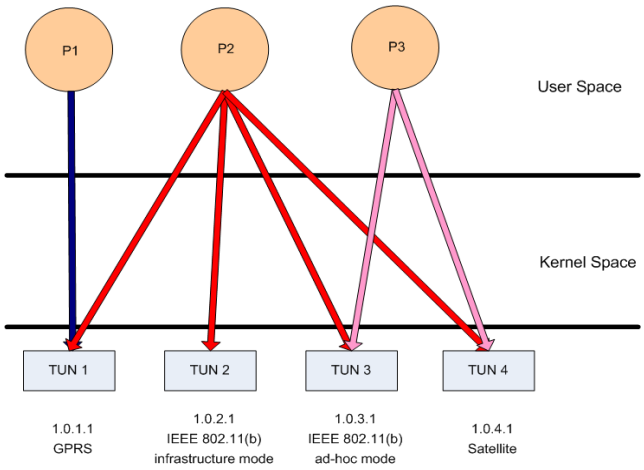


One also can press the "**Modify**" button to set up the properties of a specific radio interface. Before clicking the "**Modify**" button, one has to choose one of the entries listed in the interface table to specify which interface he/she intends to modify. If one clicks the "**Modify**" button directly without specifying an interface entry, by default the nctunsclient will invoke the dialog box of the first interface. The following figure shows an example dialog box after one clicks the "**Modify**" button.



Exploiting Multiple Heterogeneous Wireless Interfaces

As shown in the following figure, application programs running on a multi-interface mobile node (ITS car) can utilize multiple wireless interfaces to transmit/receive packets. To utilize such heterogeneous interfaces, the application programs should know the IP addresses assigned to these underlying interfaces. One should explicitly provide such information for application programs using command-line arguments. This is because so far no system calls are provided for application programs to obtain such information.



Given the IP addresses assigned to these interfaces, an application program can first create sockets for these interfaces, and then call the “bind()” system call to bind each of these sockets to each of these IP addresses. After performing these binding operations, the application program can send out packets through any desired interface by writing these packets into the corresponding socket. Similarly, the application program can receive packets from any desired interface by reading packets from the corresponding socket. With explicit binding, an application program running on a multi-interface mobile node or an ITS car can utilize multiple heterogeneous wireless interfaces at the same time.

Note that when running on a single-interface node, an application program need not bind a socket to the IP address assigned to this interface. This is because the operating system can automatically use the correct interface by looking up the routing table. On a multi-interface mobile node (and an ITS car), however, if an application program does not bind a correct IP address to a created socket, the operating system will use a default interface to transmit packets written into this socket. This result may be undesired for the application program.

Summary

In this chapter, we present the concepts of multi-interface mobile nodes and ITS cars in NCTUns. Insertion of such nodes and specification of their moving paths are illustrated. Finally, we explain how to write an application program that utilizes multiple interfaces at the same time for advanced applications.

21. IEEE 802.16(d) WiMAX Networks

The IEEE 802.16 (WiMAX) family of standards is a promising communication technology for future local and metropolitan area networks. This standard family defines the specification of the air interface for fixed broadband wireless access (FBWA) systems. Two operational modes are defined in the IEEE 802.16(d) standard: the mesh and point-to-multipoint (PMP) modes. In this chapter, we present how to conduct a simulation of IEEE 802.16(d) networks over NCTUns.

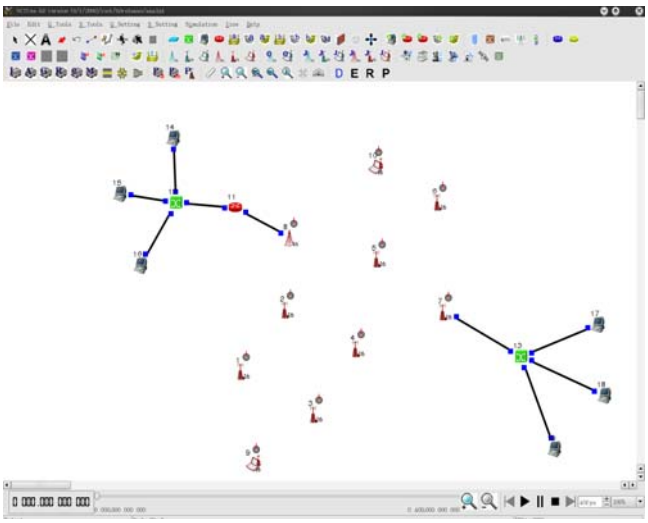
IEEE 802.16(d) Mesh Mode Concept

The IEEE 802.16(d) mesh mode is designed for constructing the next-generation wireless metropolitan area networks (Wireless-MANs). It can support multi-hop communications and allow for more flexible network topologies, as compared with the PMP (point-to-multipoint) mode.

There are two types of nodes in an IEEE 802.16(d) mesh network: mesh base station (mesh BS) and mesh subscriber station (mesh SS) nodes. A mesh BS node ( ) manages the network and connects to the backhaul network (i.e., the Internet). On the other hand, mesh SS nodes represent IEEE 802.16-capable terminal devices and can forward packets among themselves.

In NCTUns, the mesh SS node is further divided into two types. One is the mesh gateway SS node and the other is the mesh host SS node. A mesh gateway SS node ( ) can perform the routing and self-configuration functions. In addition, it can connect the mesh network to another network and route packets between the two networks. In contrast, a mesh host SS node ( ) represents a terminal device equipped with an IEEE 802.16(d) interface. Mesh host SS nodes can forward packets among themselves. However, a mesh host SS cannot connect to another network.

The following figure shows an example of the IEEE 802.16(d) mesh network. The mesh BS node connects to the Internet at the top-left via a fixed link and forms a wireless mesh network together with other mesh SS nodes. Using the forwarding capability of the mesh BS node, nodes in the mesh network can access the Internet. Moreover, taking advantage of the routing function of the mesh gateway SS node, nodes in the bottom-right subnet can access the Internet as well.

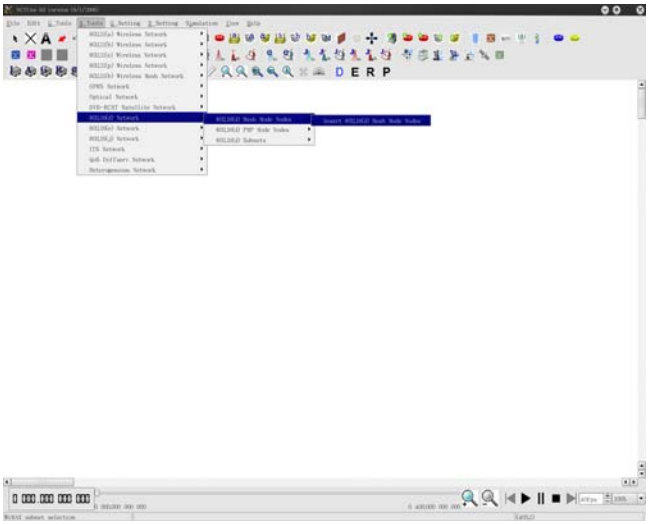


Setting IEEE 802.16(d) Mesh Networks

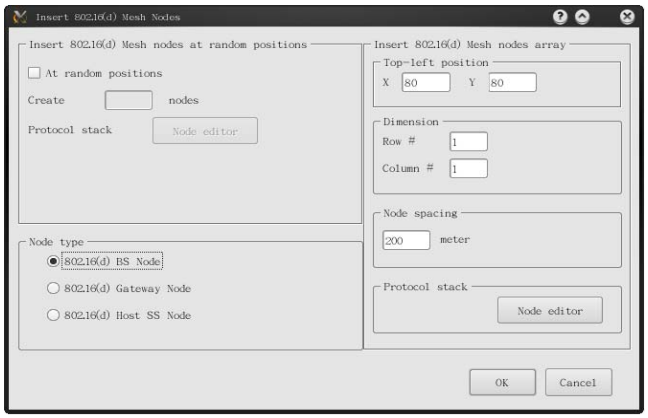
In the following, we show how to set up an IEEE 802.16(d) mesh network case using the GUI program.

Insert IEEE 802.16(d) Mesh Nodes

To deploy an IEEE802.16(d) mesh network, one can either place mesh network nodes one at a time or place a number of nodes in one step by using the following automatic deployment tool: **Menu -> N_Tools -> 802.16(d) Network -> 802.16(d) Mesh Mode Nodes -> Insert 802.16(d) Mesh Mode Nodes**.



After executing the "**Insert 802.16(d) Mesh Mode Nodes**" command, the following dialog box will be popped up. In this dialog box, one can specify (1) the type and the number of the inserted network nodes, (2) the positions where the network nodes should be placed, and (3) the protocol-specific setting applied to each node.



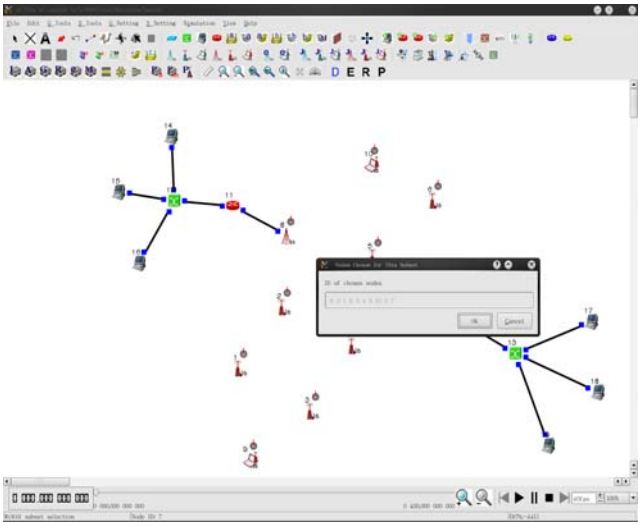
Specify and Manage IEEE 802.16(d) Mesh Subnets

To save a user's time and effort, the GUI program tries to automatically identify subnets and generate IP addresses for each layer-3 interface. This can be done for fixed networks because nodes in such a network are connected. However, for wireless networks in which nodes are not connected, the GUI program has no information to identify the subnet relationship and thus IP addresses cannot automatically be generated for wireless nodes.

In order to automatically generate IP addresses for the nodes in an IEEE 802.16(d) mesh network, one should first specify subnets before entering the "**Run Simulation**" mode. To specify an IEEE 802.16(d) mesh subnet, one can first left-click the "form subnet" button ( ) on the tool bar. Next, he (she) can left-click multiple node icons in the working area to group together a set of nodes to form a subnet. After selecting one or more subnet members (i.e., network nodes), the user can right-click anywhere in the working area to terminate the form-subnet action. The following dialog box will then show up to ask the user if he (she) really wants to terminate this action.

The created subnets can be managed via the "**Subnet Management**" command, which is located at **Menu -> N_Tools -> 802.16(d) Network -> 802.16(d) Subnets -> Manage 802.16(d) Subnets**.

After specifying subnets, the IP addresses of mesh network nodes can be automatically generated and assigned by the GUI program. However, to correctly generate routing paths for these nodes, one should further specify gateways for the formed subnets. To do so, one can left-click the "**Specify**

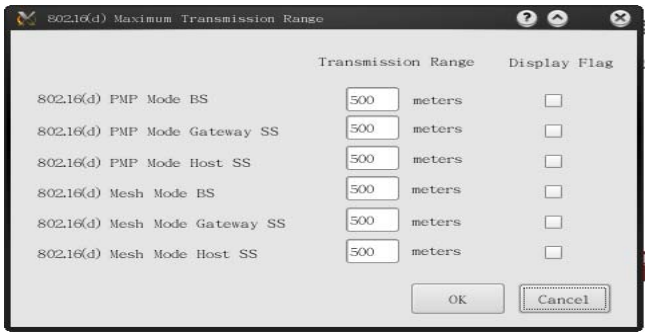


The subnet formation dialog box shows the IDs of the selected nodes to form a subnet.

Gateway" button in the dialog box of the "**subnet management**" command. In the "Specify Gateway for a Subnet" dialog box, one can add a gateway entry, modify it, or delete it. A gateway entry is made up of three fields: the source subnet, the destination subnet, and the ID of the gateway node used by the source subnet for routing packets to the destination subnet.

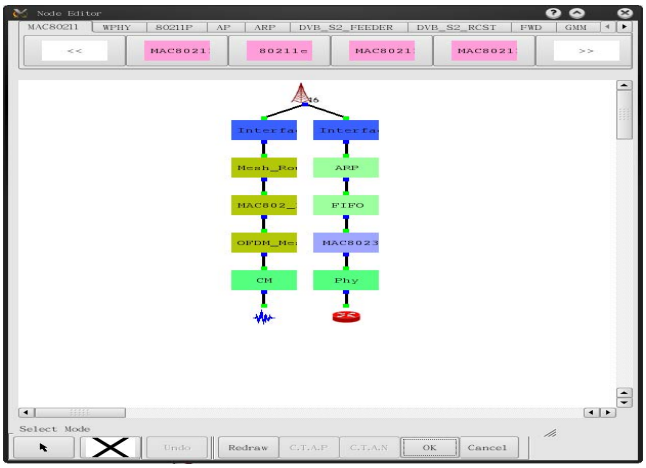
Specify Maximum Transmission Range For IEEE 802.16(d) Mesh Nodes

One can specify the maximum transmission range for IEEE 802.16(d) mesh nodes via **Menu -> N_Setting -> 802.16(d) Network -> Set Maximum Transmission Range For 802.16(d) Stations** command. Then, the maximum transmission range for each type of nodes can be specified in the following dialog box.



IEEE 802.16(d) Mesh Network Protocol Stack

The settings of IEEE 802.16(d)-related modules can be specified via the "**Node Editor**." The following figure shows the default protocol stack of a mesh BS node. By double-clicking on a module icon, its corresponding parameter dialog box will be popped up. For example, one can specify the maximum MAC-layer transmission queue length in the parameter dialog box of the MAC802_16_MeshBS module. As for the physical-layer settings, parameters such as the default channel ID and the receive sensitivity can be specified in the OFDM_Mesh module's parameter dialog box.

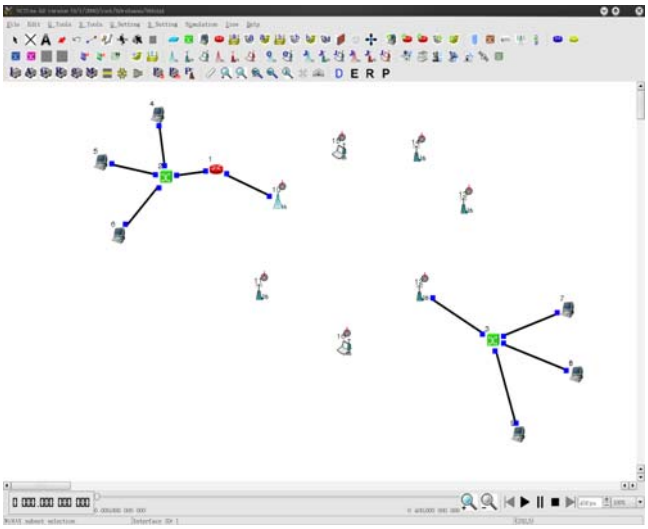


IEEE 802.16(d) PMP Mode Concept

The IEEE 802.16(d) PMP mode is a last-mile technology to replace traditional wired solutions. The downlink, from the base station (BS) node to subscriber station (SS) nodes, operates on a PMP basis. On the other hand, the uplink is shared by all SS nodes. In this mode, traffic from a SS node to the Internet or between two SS nodes must be routed through the PMP BS node.

The PMP BS node ( ) is responsible for allocating network resources and coordinating uplink transmissions. As in the IEEE 802.16(d) mesh network described previously, in NCTUns the PMP SS node is subdivided into two types: the PMP gateway SS and the PMP host SS nodes. A PMP gateway SS node ( ) can perform the self-configuration and routing functions. Besides, it can act as router to connect the IEEE 802.16(d) PMP network with another network. As for a PMP host SS node ( ), this node type is used to represent a terminal device equipped with an IEEE 802.16(d) PMP mode radio. Such a node cannot act as a router to connect to another fixed network.

The following figure shows an example of IEEE 802.16(d) PMP networks. In this network, there are one PMP BS node, one PMP gateway SS node, and a number of PMP host SS nodes. The PMP BS node connects to the Internet (at the top-left) via a fixed link while the PMP gateway SS node connects to a subnet (at the bottom-right) via a fixed link. Through the routing functions of the PMP BS and gateway SS nodes, the hosts on the Internet, in the PMP network, and in the bottom-right subnet can communicate with each other.

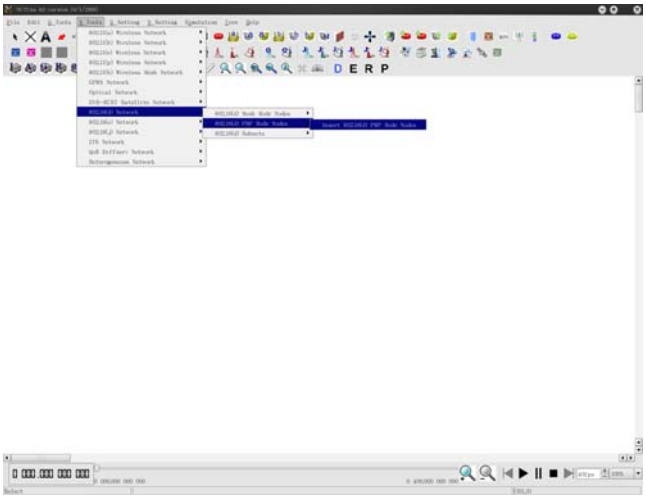


Setting IEEE 802.16(d) PMP Networks

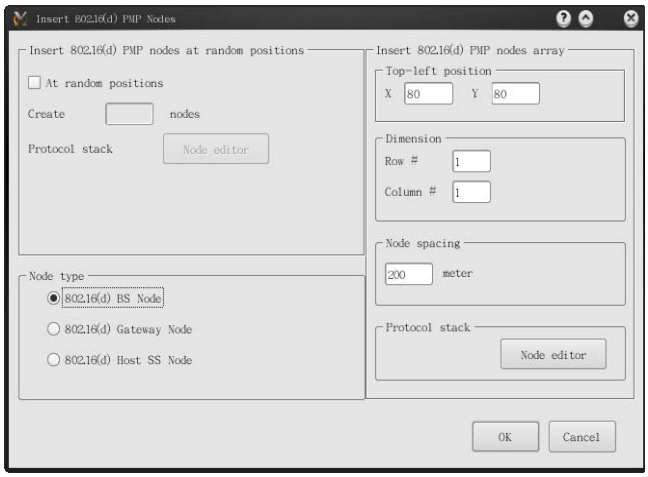
In the following, we show how to use the GUI program to generate an IEEE 802.16(d) PMP network simulation case.

Insert PMP Nodes

To deploy an IEEE 802.16(d) PMP network, one can either insert IEEE 802.16(d) PMP nodes one at a time or insert a number of nodes in one single step by the **Insert 802.16(d) PMP Mode Nodes** command. The location of this command is **Menu -> N_Tools -> 802.16(d) Network -> 802.16(d) PMP Mode Nodes -> Insert 802.16(d) PMP Mode Nodes**.



In the dialog box shown in the following figure, one can specify (1) the type and the number of the inserted nodes, (2) the positions where the nodes should be placed, and (3) the protocol-specific settings that should be applied to each node.



Specify and Manage IEEE 802.16(d) PMP Subnets

Like in the IEEE 802.16(d) mesh network, the GUI user must use the "form subnet" tool ( ) to group together the PMP BS node and the PMP SS nodes to form a subnet. Doing so allows the GUI program to automatically generate IP addresses for these nodes, saving the user much time and effort.

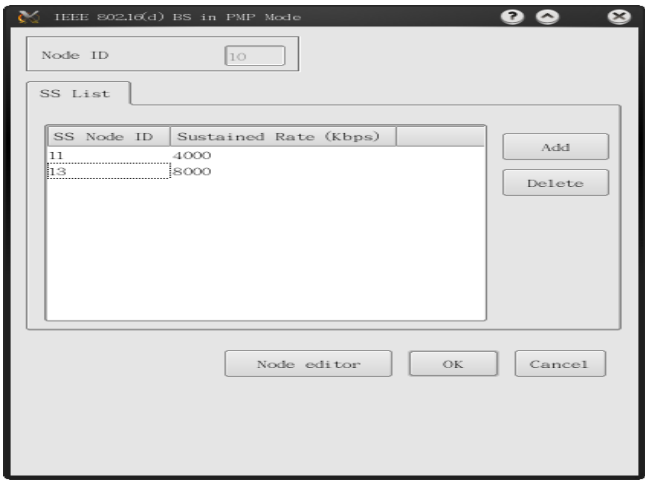
Specifying and managing IEEE 802.16(d) PMP subnets uses a procedure similar to that for IEEE 802.16(d) mesh subnets. Please refer to the previous section "**Manage IEEE 802.16(d) Mesh Subnets**" for detailed information.

Specify Maximum Transmission Range For IEEE 802.16(d) PMP Nodes

Specifying the maximum transmission range for IEEE 802.16(d) PMP nodes uses a procedure similar to that for mesh nodes. Please refer to the previous section "**Specify Maximum Transmission Range For IEEE 802.16(d) Mesh Nodes**" for detailed information.

Specify Sustained Rates For IEEE 802.16(d) PMP SS Nodes

Currently the data scheduler used in the PMP BS node only supports unsolicited grant service (UGS) flows. One can double-click the icon of a PMP BS node to invoke its dialog box, shown in the following. Then, he (she) can specify the sustained rate in Kbps allocated for each PMP SS node.



IEEE 802.16(d) PMP Network Protocol Stack

Currently, there are no GUI-adjustable parameters for PMP-related modules. If a user wants to change the default parameter values used inside a PMP-related module, he (she) can modify the source code of the module (which is included in the NCTUns package) and re-compile the NCTUns simulation engine program.

Summary

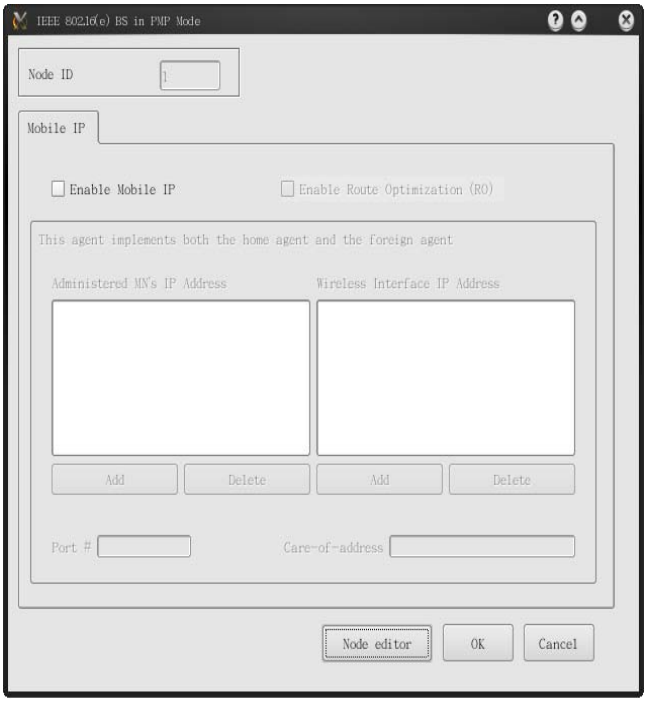
In this chapter, we present an conceptual introduction to IEEE 802.16(d) networks and the necessary steps for simulating these networks over NCTUns. Also, we explain the usages of important commands and dialog boxes to help users simulate such networks correctly.

22. IEEE 802.16(e) WiMAX Networks

The IEEE 802.16(e) specification defines a novel next-generation broadband mobile wireless access network, which amends the IEEE 802.16(d) standard released in year 2004. The 802.16(e) differs from the 802.16(d) in two aspects. First, the 802.16(e) adopts the Orthogonal Frequency Division Multiple Access (OFDMA) technology to manage link bandwidth while the 802.16(d) uses the Orthogonal Frequency Division Multiplexing (OFDM) to do it. Second, the 802.16(e) adds several mechanisms, such as, timing adjustment, continuous ranging, Mobile Station (MS) handoff, etc., to support user mobility. NCTUns 6.0 supports the IEEE 802.16(e) network. In this chapter, we present how to conduct a simulation of an IEEE 802.16(e) network using the GUI program.

IEEE 802.16(e) PMP Mode Concept

An IEEE 802.16(e) PMP-mode network is composed of two types of nodes. The first is the Base Station (BS) (), which is responsible for allocating network resources and coordinating uplink transmissions, while the second is the Mobile Station (), which is a mobile node that is equipped with an 802.16(e) radio and can run application on it. Since the IEEE 802.16(e) network is an "All IP" network, to support user mobility, it employs the mobile IP scheme to deal with the issues of user mobility at the network layer. The following two figures show the dialog boxes of an 802.16(e) BS node and an 802.16(e) MS node, respectively. The detailed instructions for configuring Mobile IP for this network can be found in the "Mobile IP" chapter.

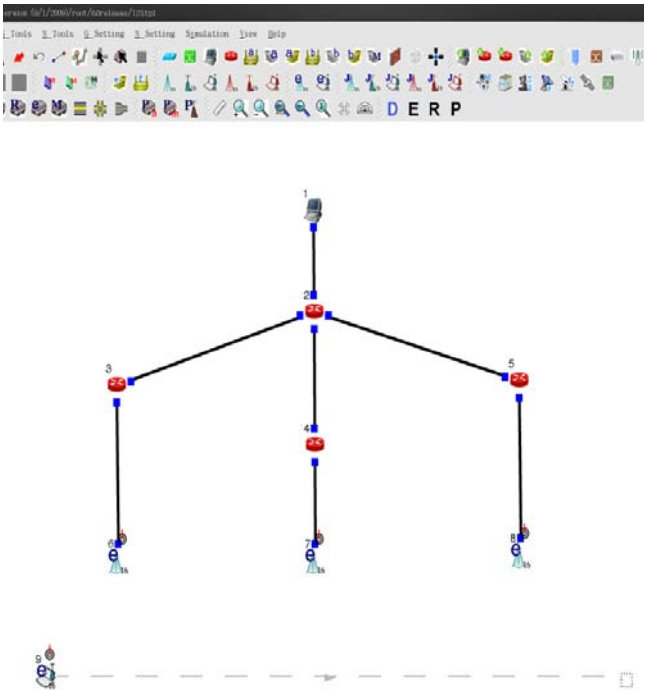


IEEE 802.16(e) PMP-mode Base Station

IEEE 802.16(e) PMP-mode Mobile Station

The following figure illustrates an example of the IEEE 802.16(e) PMP network, which comprises three PMP BS nodes and one PMP MS node. The three BS nodes manage

three different subnets, respectively. As such, they are inter-connected with routers. In this simulation case, the MS node periodically transmits data packets to a host, which is connected to this 802.16(e) network via a fixed line, and moves towards the right at a constant speed.



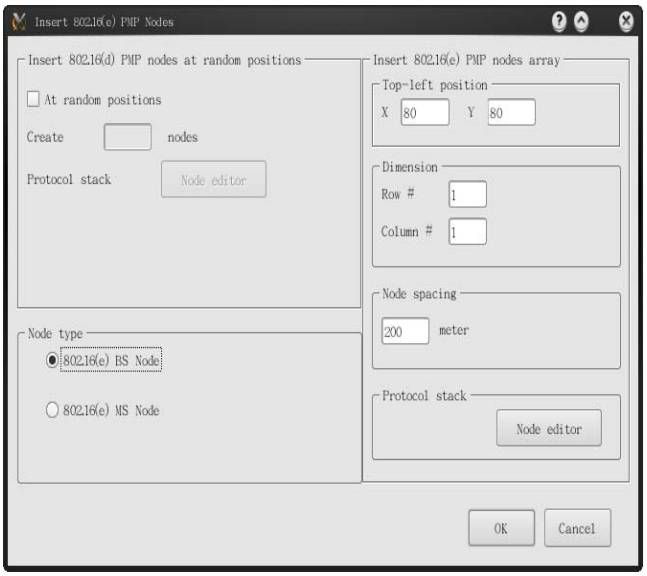
Setting IEEE 802.16(e) PMP Networks

In the following, we show how to use the GUI program to generate an IEEE 802.16(e) PMP network simulation case.

Insert PMP Nodes

To deploy an IEEE 802.16(e) PMP network, one can either insert IEEE 802.16(e) PMP nodes one at a time or insert a number of nodes in one single step by using the **"Insert 802.16(e) PMP Mode Nodes"** command. The path for launching this command is "**Menu -> N_Tools -> 802.16(d) Network -> 802.16(e) PMP Mode Nodes -> Insert 802.16(e) PMP Mode Nodes**."

The following dialog box shows the layout of the **"Insert 802.16(e) PMP Mode Nodes"** command. As can be seen, one can specify (1) the type and the number of the inserted nodes, (2) the positions where the nodes will be placed, and (3) the protocol-specific settings that are to be applied to each node.

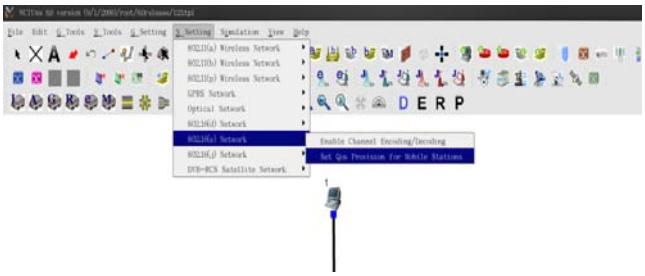


Specify and Manage IEEE 802.16(e) PMP Subnets

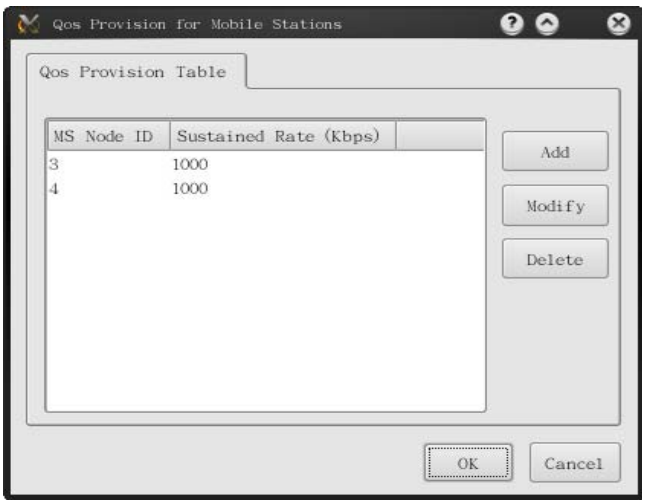
Like in the IEEE 802.16(d) mesh network, the GUI user must use the "form subnet" tool ( ) to group a PMP BS node and a number of PMP SS nodes together to form a subnet. Doing so allows the GUI program to automatically generate IP addresses of these nodes, saving the user much time and effort. The created subnets can be managed via the "**Subnet Management**" command, which is located at **Menu -> N_Tools -> 802.16(e) Network -> 802.16(e) Subnets -> Manage 802.16(e) Subnets**.

Set QoS Provision For Mobile Stations

The IEEE 802.16(e) network is QoS-aware. As such, before starting simulation, one ought to specify the QoS provision setting for each simulated MS node using the "**Set Qos Provision for Mobile Stations**" command. The path of this command is shown as follows: **Menu -> N_Setting -> 802.16(e) Network -> Set Qos Provision for Mobile Stations.**

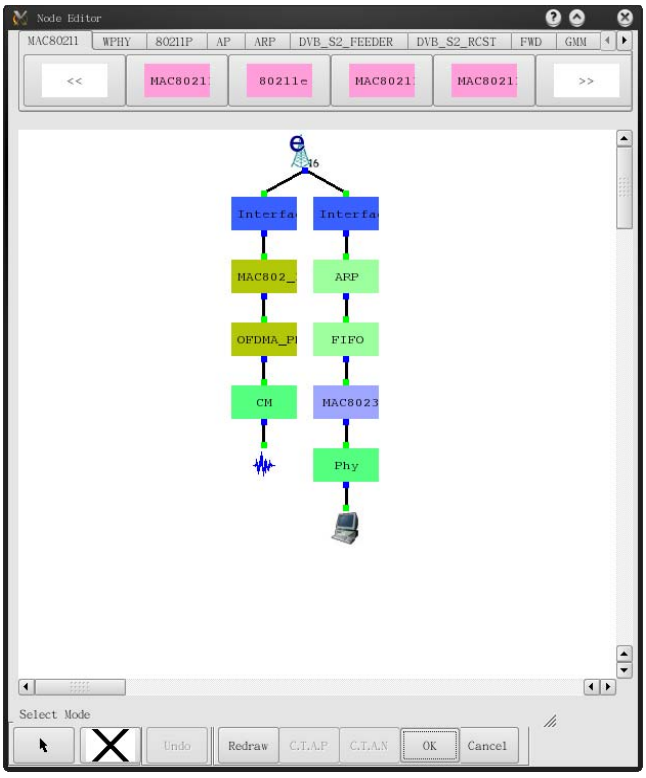


The following figure shows the format of the MS node QoS provision table. Note that the current IEEE 802.16(e) implementation in NCTUns only supports the best-effort traffic (Un-granted service). As such, the only parameter required for each MS node's QoS provision is the "sustained rate (in Kbps)," which denotes the maximum link bandwidth that this MS node is allowed to use.



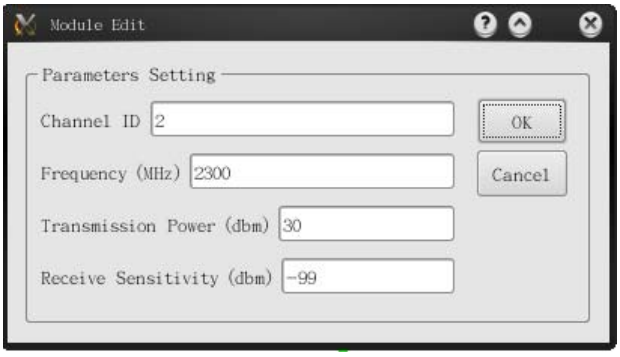
IEEE 802.16(e) PMP Network Protocol Stack

The settings of IEEE 802.16(e)-related protocol modules can be specified via the "**Node Editor**." The following figure shows the default protocol stack of an 802.16(e) BS node.



The protocol stack of an IEEE 802.16(e) BS Node

By double-clicking an icon of a module inside the protocol stack, the dialog box for the module will be popped up. For example, to specify the physical-layer parameters, such as the channel ID, operating frequency, transmission power, and the sensitivity for received signals, one can double-click the OFDMA_PMPBS_WIMAX module icon to invoke its dialog box, which is shown as follows.



The dialog box of the OFDMA_PMPBS_WIMAX module

Summary

In this chapter, we conceptually introduce the IEEE 802.16(e) network and present the steps required to configure a network case of this new network type over NCTUns. In addition, several useful commands and important dialog boxes for this network type are also explained.

23. IEEE 802.16(j) WiMAX Networks

The IEEE 802.16(j) specification is gaining much attention recently due to its several advantages over the preceding IEEE 802.16(e) network. In this network, with the multi-hop capability, a packet is allowed to traverse two hops through relay stations to reach its destination node. Thus, by properly arranging the transmission path of a packet, the capacity of the network and the signal quality experienced by users can be greatly improved against other communication technologies.

The IEEE 802.16(j) relay-mode specification defines two operational modes: the transparent mode and the non-transparent mode. NCTUns supports both of these two operational modes. In this chapter, we present the detailed GUI operations to conduct simulations of the IEEE 802.16(j) transparent-mode and non-transparent-mode networks.

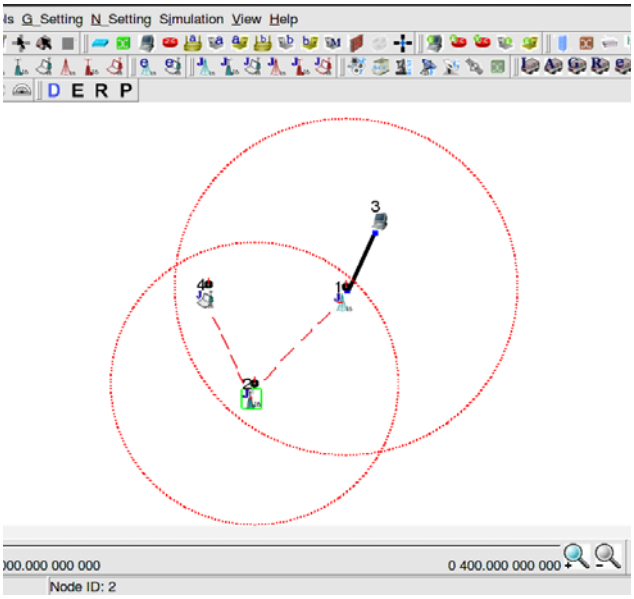
IEEE 802.16(j) Transparent Mode Concept

An IEEE 802.16(j) transparent mode network consists of three types of nodes: the Transparent Mobile Relay Base Station (TMR-BS) ( ), Transparent-Relay Station (T-RS) ( ) and Transparent-Mobile Station (T-MS) ( ) . A TMR-BS, has the same role as the one in the conventional PMP network. In addition to connecting to the backhaul network, it also acts as a central controller in the network to allocate link bandwidth for the T-RSs and T-MSs that it manages.

On the other hand, a T-RS simply forwards incoming data for its neighboring nodes and leaves the scheduling of these data to the TMR-BS. Therefore, the design complexity of a T-RS can be greatly reduced, which significantly decreases the deployment cost of the whole network. The main objective of deploying T-RSs in the network is to increase the overall capacity of the whole network. This is accomplished by dividing a non-line-of-sight packet transmission into two line-of-sight packet transmissions. Since these two line-of-sight packets can be transmitted at a higher data rate due to better signal qualities, the overall capacity of the network can be increased.

In the current implementation, for both the transparent mode and non-transparent mode, a relay station must be fixed and cannot be mobile. In addition, in the non-transparent mode, at most four relay stations can exist; otherwise, the base station will not have enough bandwidth to support all of them. This means that in such a condition, a TCP flow set up between the base station and a mobile station through a relay station may get very little bandwidth and starve.

The following figure illustrates a typical example of IEEE 802.16(j) relay WiMAX network operating in the transparent mode. In this example network, the TMR-BS connects to the internet via a fixed link and forms an 802.16(j) transparent-mode network together with other T-RSs and T-MS.



The dotted red circles show the transmission ranges of the TMR-BS and the T-RS, respectively. As illustrated in the above figure, both the T-MS and T-RS are within the transmission range of the TMS-BS. The distance between the TMR-BS and the T-MS is purposely set so that it is very close to the transmission range of the TMR-BS. This arrangement makes the signal quality of the TMR-BS sensed by the T-MS very weak (just a bit higher than the receive power threshold of the T-MS). Another way to make this condition is to place the T-MS behind an obstacle so that there is no direct line-of-sight between the TMR-BS and the T-MS.

In this condition, a traditional BS has two alternatives to transmit/receive the packets to/from the T-MS. One is that the TMR-BS maintains its original modulation/coding scheme used on the direct link between itself and the T-MS. However, due to the decreased signal quality over the link, the bit error rates of the received data packets on both nodes will significantly increase. As a result, the goodput over the

direct link between the TMR-BS and the T-MS will drastically decrease. The other is that the TMR-BS can use a more robust modulation/coding scheme (which usually provides a lower data rate) for this link. The disadvantage of this option is the reduction of the number of bits carried in a physical-layer symbol, which thus decreases the effective MAC-layer data rate over this link. Obviously, there is a trade off between the bit error rates of received packets and the system throughputs in traditional cellular networks.

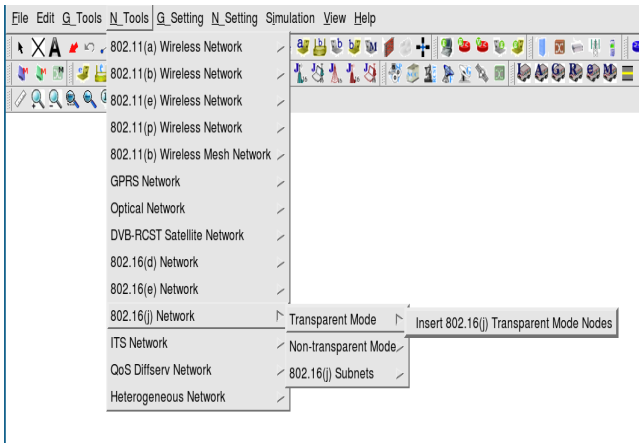
This problem, however, can be overcome in an 802.16(j) relay network with the aid of relay stations. In the above case, instead of using the direct link between itself and the T-MS, the TMR-BS can communicate with the T-MS via the T-RS, i.e., its packets can be sent to the T-MS through the T-RS. Due to shorter distances between the TMR-BS and the T-RS and between the T-RS and the T-MS, these nodes can adopt modulation schemes that offer higher data rates while maintaining acceptable bit error rates for received packets on the wireless links. Therefore, it is possible to achieve higher network capacity in an 802.16(j) transparent mode network.

Setting IEEE 802.16(j) Transparent Mode Networks

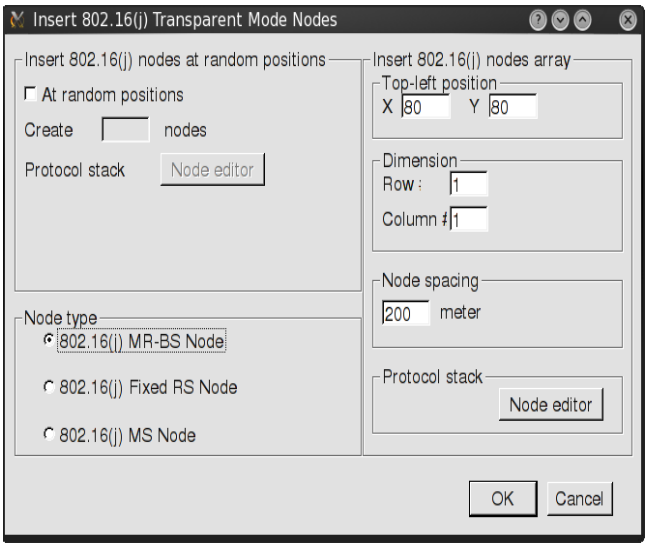
In the following, we demonstrate how to use the GUI program to conduct an IEEE 802.16(j) transparent mode network simulation case.

Insert IEEE 802.16(j) Nodes

To deploy an IEEE 802.16(j) transparent mode network, one can either insert IEEE 802.16(j) transparent mode nodes one by one or deploy a number of nodes in batch by using the automatic deployment tool.



The following figure shows the layout of the **"Insert 802.16(j) Transparent Mode Nodes"** tool, whose path is "**Menu -> N_Tools -> 802.16(j) Network -> Transparent Mode-> Insert 802.16(j) Transparent Mode Nodes**." By using this tool, one deploys 802.16(j) transparent mode nodes at random locations or in a grid manner. As one sees, one can also specify 1) the type and the number of nodes to be deployed and 2) the protocol stack setting of the inserted nodes by clicking the **"Node Editor"** button.

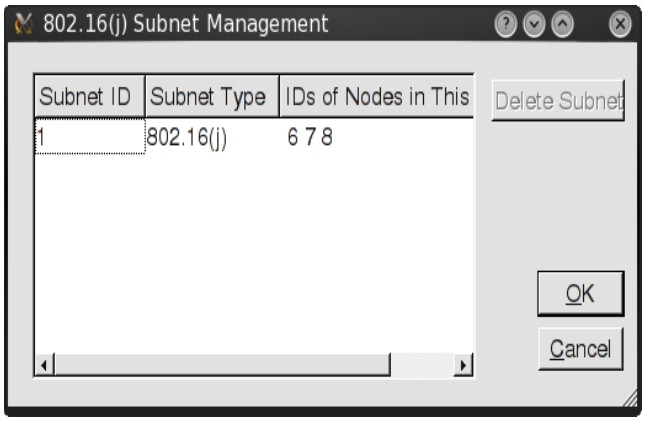


Specify and Manage IEEE 802.16(j) Transparent Mode Network Subnets

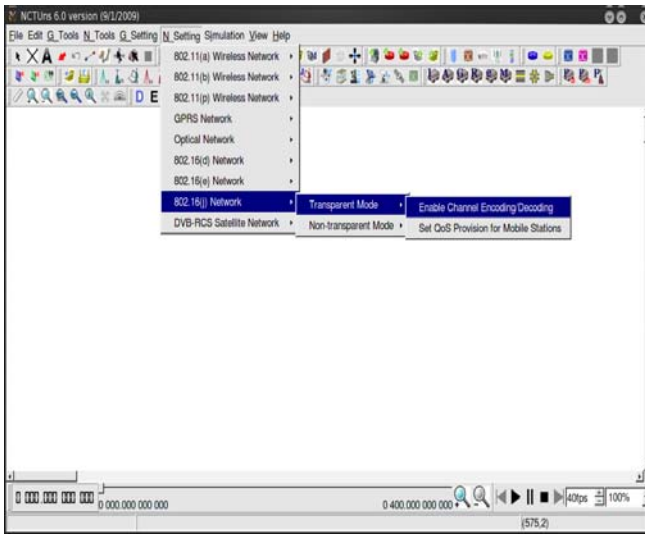
To automatically generate the IP addresses for the wireless nodes in an IEEE 802.16(j) transparent mode network, the subnet must be explicitly specified using the "form subnet" tool ( ) on the tool bar. The usage of this tool is described here. One first clicks the "form subnet" icon on the tool bar and then chooses the nodes that he (she) wants to group together to form a subnet by left-clicking their icons in the working area. To end the grouping action, one can right-click the background of the working area of the GUI program. Doing so will pop up a dialog box that shows the IDs of the nodes that are chosen to form the subnet.

One can also manage the created subnets via the "**Manage 802.16(j) Subnet**" command, which is located at "**Menu -> N_Tools -> 802.16(j) Network -> 802.16(j) Subnets".** If one wants to delete a created subnet, he (she) can simply click the **"Delete Subnet"** command, which is shown in the dialog box below.

Set the Channel Encoding / Decoding Option for the Transparent Mode WiMAX Relay Network



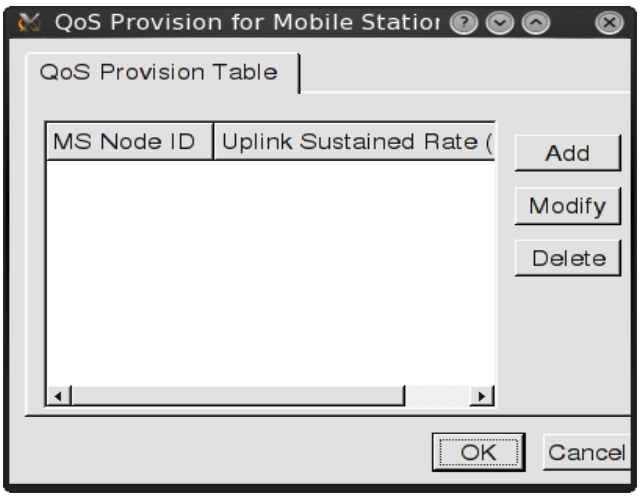
To enable/disable the channel encoding/decoding function, one can turn on the **"Enable Channel Encoding/Decoding"** flag. As shown in the following figure, the path of the flag is "**Menu -> N_Setting -> 802.16(j) Network -> Transparent Mode -> Enable Channel Encoding/Decoding."** By default, the channel encoding/decoding option is turned off by the GUI program.



Set QoS Provision For Transparent Mobile Stations

The IEEE 802.16(j) network is QoS-capable. However, the current IEEE 802.16(j) network implementation in NCTUns only supports the best-effort service. Therefore, the only QoS parameter required for each MS node's QoS provision is the maximum uplink sustained rate (in Kbps). As a rule of thumb, the sum of the uplink bandwidth allocated to each MS should not exceed the maximum bandwidth provided by the TMR-BS of the network. For this reason, one should carefully calculate and determine the uplink sustained rate for each MS in a simulation case.

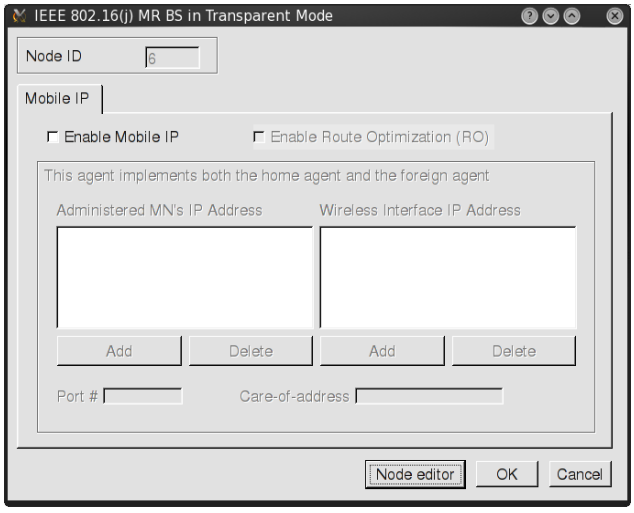
Before starting the simulation, one should specify the QoS provision setting for each simulated MS node using the "**Set Qos Provision for Mobile Stations**" command. The path of this command is shown as follows: **Menu -> N_Setting -> 802.16(j) Network -> Transparent Mode -> Set Qos Provision for Mobile Stations.** The following figure shows the screenshot of this tool. When using this tool, one is required to enter the Node ID of the specified MS and the desired uplink sustained rate (in Kbps) for the specified MS.

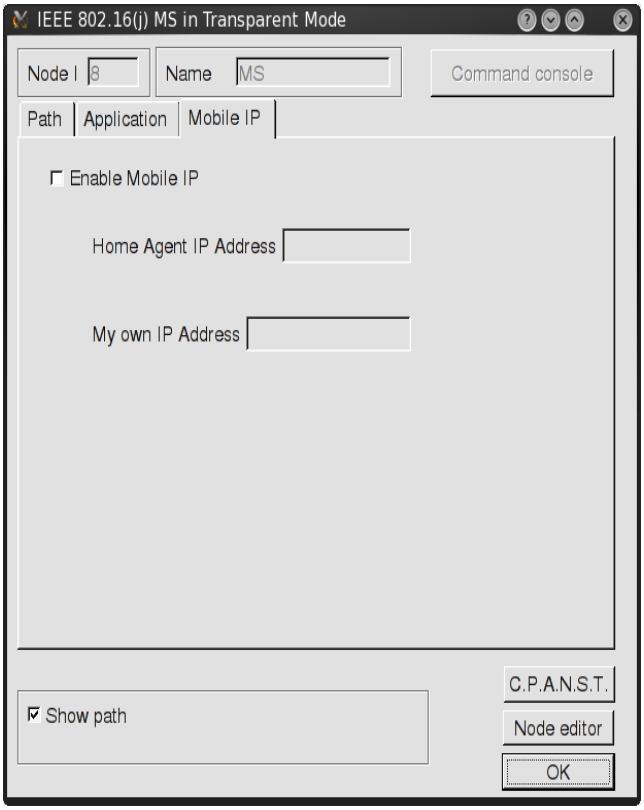


Set Mobile IP For Transparent Mobile Relay Base Stations and Transparent Mobile Station

The mobile IP mechanism is used in NCTUns to support the roaming between different TMR-BSs. It is easy for a user to configure the mobile IP mechanism in NCTUns. One can configure the mobile IP setting for a TMR-BS via the [Mobile IP] tab on its dialog box. The panel of the [Mobile IP] tab is shown as follows. To enable the mobile IP function, one should tick the **"Enable Mobile IP"** option on the panel. The setting of the mobile IP mechanism has been explained in a previous chapter. To save space, we do not explain it again here.

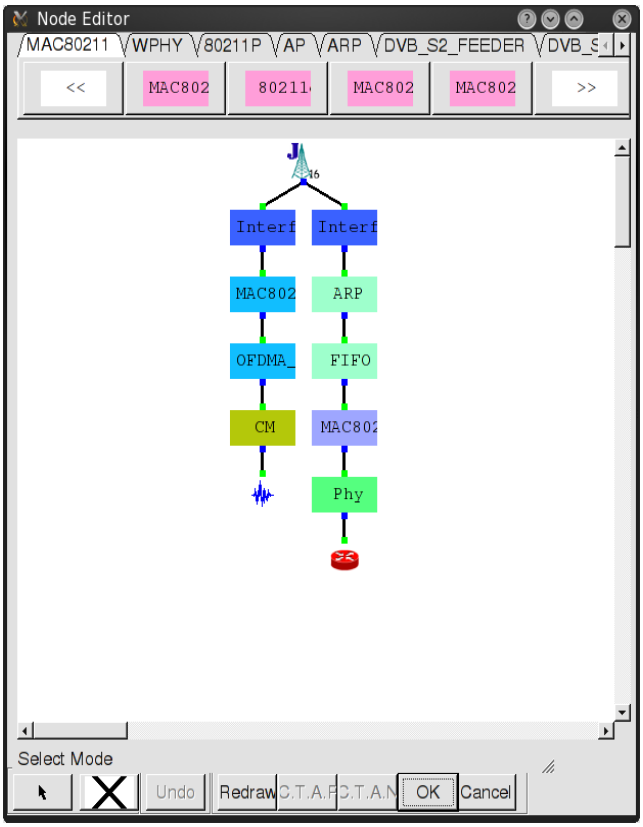
Similar to that of a TMR-BS, the mobile IP setting for a T-MS can be configured by launching the **"Mobile IP"** tab in its dialog box. The user should first tick the **"Enable Mobile IP"** option to enable the mobile IP function. He (she) then fills in the **"Home Agent IP Address"** and **"My Own IP Address"** fields, respectively. The former refers to the IP address of the TMR-BS in the same subnet as this T-MS, while the latter refers to the IP address of this T-MS. The functions of the Path and Application tabs are the same as those of an IEEE 802.11(b) mobile node. Thus, we do not explain them to save space.



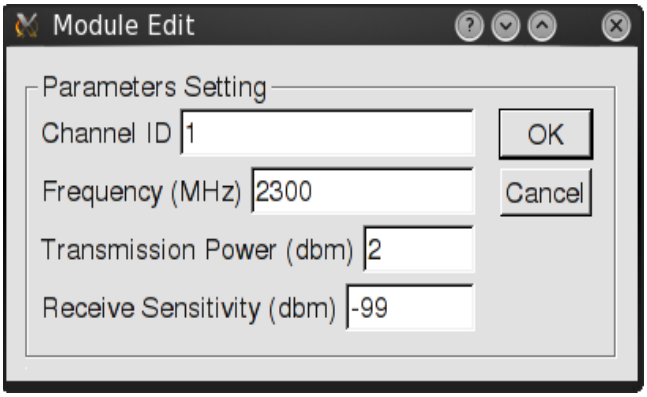


IEEE 802.16(j) Network Protocol Stack

The settings of IEEE 802.16(j)-related protocol modules can be specified via the "**Node Editor**." The following figure shows the default protocol stack of an 802.16(j) TMR-BS node.



By double-clicking the icon of a module inside the node editor, the dialog box for the module will be popped up. For example, to specify the physical-layer parameters, such as the channel ID, operating frequency, transmission power, and the sensitivity for received signals, one can double-click the **OFDMA_** module icon to invoke its dialog box, which is shown as follows.



Setting of Physical Layer Parameters for IEEE 802.16(j) Transparent Mode Nodes

The above figure shows the default settings of the physical layer parameters for an IEEE 802.16(j) node. One may need to change the default values of these parameters (e.g., the Channel ID parameter) based on the simulated network topology.

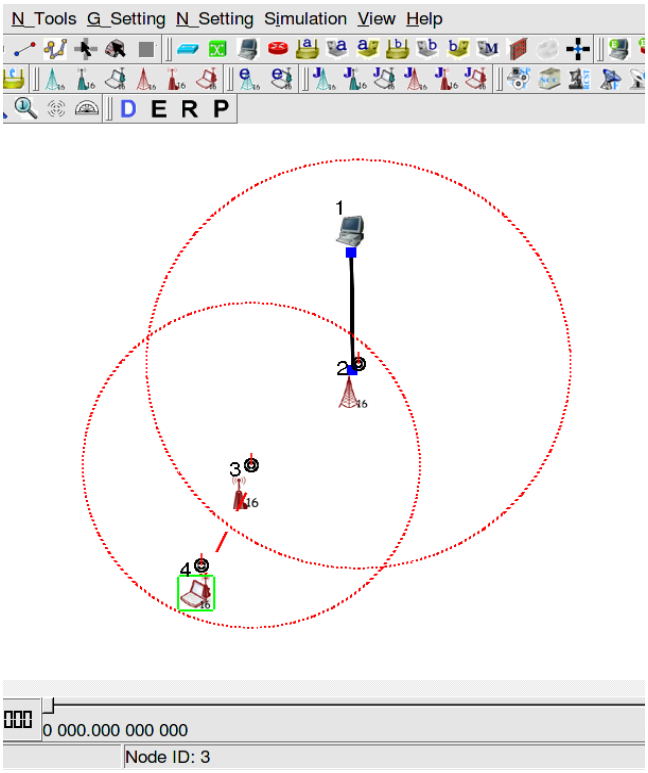
According to the 802.16(j) standard, the communications among all the transparent mode stations within the same cell should take place on the same channel. Therefore, one must make sure that the used channel IDs of the T-RSs and T-MSs are set to the Channel ID used by the TMR-BS. Also, the user may need to adjust the transmit power of the 802.16(j) nodes to construct a specific network case. In practice, the transmit power of a TMR-BS is usually set to a value higher than those of T-RSs and T-MSs.

IEEE 802.16(j) Non-Transparent Mode Concept

An IEEE 802.16(j) non-transparent mode network differs grealy from an 802.16(j) transparent mode network. The key difference between them is how the framing information is transmitted. Unlike the T-RS, in an IEEE 802.16(j) non-transparent mode network, non-transparent relay stations (NT-RS) ( ) do not simply forward the incoming data packets. Instead, a NT-RS transmits its own frame header information (which contains essential control message and data scheduling information) and thus it can schedule its own control messages and data transmissions. An NT-RS could either operate in the centralized mode or in the distributed mode. In the former mode, the resouce allocations for all nodes in the network are scheduled on the NT MR-BS ( ), while in the latter mode, NT-RSs can make their own scheduling decisions for the NT MS ( ) associated with them.

Due to these characteristics of NT-RSs, a non-transparent mode network can operate over a network topology that contain two more hops. Therefore, the main advantage of this mode is extending the signal coverage of a BS. In the current implementation of NCTUns, an 802.16(j) non-transparent mode network is restricted to only two hops and use the centralized scheduling.

The following figure illustrates a typical example of IEEE 802.16(j) relay WiMAX network operating in the non-transparent mode. As shown in the figure, the NT MR-BS connects to a host via a fixed link and forms a subnet together with other NT-RSs and NT-MSs. In this example, the NT-MS is located out of the signal coverage of the NT MR-BS; thus, there is no direct communication between the NT MR-BS and NT-MS. To exchange packets between the NT MR-BS and NT-MS, an NT-RS should be used as an intermediate node to forward packets.



Setting IEEE 802.16(j) Non-Transparent Mode Networks

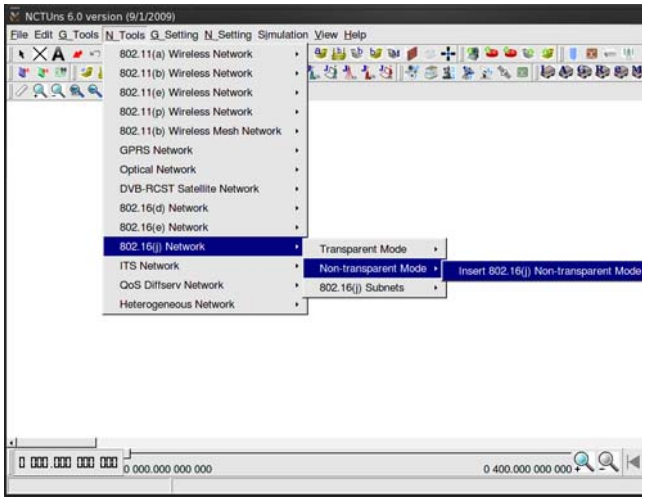
In the following, we show how to use the GUI program to conduct an IEEE 802.16(j) non-transparent mode network simulation case.

Insert IEEE 802.16(j) Non-transparent Mode Nodes

To deploy an IEEE 802.16(j) non-transparent mode network, one can either insert IEEE 802.16(j) non-transparent mode nodes one at a time or place them in batch by using the automatic deployment tool. As shown in the following figure, the path of this tool is: "**Menu -> N_Tools -> 802.16(j) Network -> Non-transparent Mode-> Insert 802.16(j) Non-transparent Mode Nodes**." By using this tool, the nodes can be deployed in a random manner or in a grid manner.

Specify and Manage IEEE 802.16(j) Non-transparent Mode Network Subnets

To automatically and correctly generate the IP addresses for the IEEE 802.16(j) non-transparent mode nodes, the subnet relationship of these nodes should be explicitly specified using the "form subnet" button ( ) , which is on the tool bar. The procedures to specify and manage IEEE 802.16(j) non-transparent mode subnets are the same as those to



specify and manage 802.16(j) transparent mode subnets. Reader can refer to the previous section **"Specify and Manage IEEE 802.16(j) Transparent Mode Network Subnets"** for detailed information.

Set QoS Provision For Non-transparent Mobile Stations

The IEEE 802.16(j) network is QoS-capable. However, the current IEEE 802.16(j) network implementation in NCTUns only supports the best-effort service. Therefore, the only QoS parameter required for each NT-MS node's QoS provision is the maximum uplink sustained rate (in Kbps). As a rule of thumb, the sum of the uplink bandwidth allocated to each NT-MS should not exceed the maximum bandwidth provided by the NT MR-BS of the network. For this reason, one should carefully calculate and determine the uplink sustained rate of each NT-MS in a simulation case.

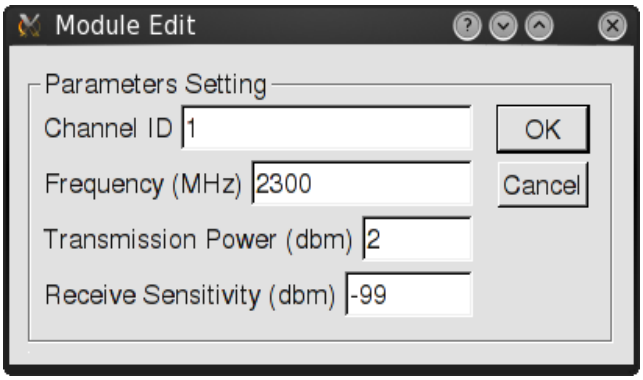
Before starting the simulation, one should specify the QoS provision setting for each NT-MS node using the "**Set Qos Provision for Mobile Stations**" command. The path of this command is shown as follows: **Menu -> N_Setting -> 802.16(j) Network -> Non-transparent Mode -> Set Qos Provision for Mobile Stations.** The following figure shows the screenshot of this tool. When using this tool, one is required to enter the Node ID of the specified NT-MS and the desired uplink sustained rate (in Kbps) for the specified NT-MS.

Set Mobile IP For Non-transparent Mobile Relay Base Stations and Non-transparent Mobile Station

The procedures to configure the Mobile IP settings for NT-MSs and NT MR-BSs are the same as those for T-MSs and TMR-BSs. Readers can refer to the previous section **" Set Mobile IP For Transparent Mobile Relay Base Station and Transparent Mobile Station"** for detailed information.

Setting of Physical Layer Parameters for IEEE 802.16(j) Non-transparent Nodes

The settings of IEEE 802.16(j)-related protocol modules can be specified via the "**Node Editor**." Readers can refer to the previous section "IEEE 802.16(j) Protocol Stack" for detailed information. The following figure shows the default settings of the physical layer parameters for an IEEE 802.16(j) non-transparent mode node. One may need to change the default values of these parameters (e.g., the Channel ID parameter) based on the simulated network topology.

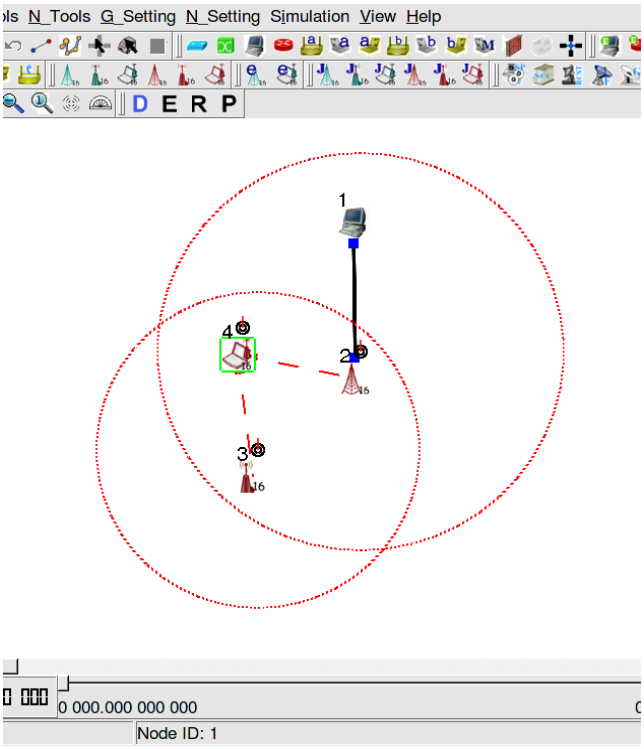


According to the 802.16(j) standard, the NT MR-BS and NT-RSs in the same cell can use different frequencies to transmit/receive control messages and data. However, the current implementation of NCTUns only allows all non-transparent stations in the same cell to use the same channel for communications. For this reason, one must ensure that the channels used by the NT-RSs and NT-MSs are set to that used by the NT MR-BS.

This basic implementation has a drawback on network performances. As shown in the following figure, if a NT-MS is located within the signal coverage of a NT MR-BS and those of several NT-RSs (the red dash lines indicate that the NT-MS can sense signals from both the NT MR-BS and the NT-RS), the NT-MS may not be able to receive any control messages and data transmitted from these nodes.

The reason is that because in an 802.16(j) non-transparent mode network both NT MR-BSs and NT-RSs should transmit their own control messages. The 802.16(j) standard does not specify a mechanism to coordinate these message and data transmissions on the time axis. Thus, the message and data transmissions of NT MR-BSs and NT-RSs may overlap with each other on the time axis. In this condition, control messages and data transmitted by these nodes are likely to collide with each other at the NT-MS. This will make the NT-MS fail to receive control messages necessary for its network operation. As a result, the NT-MS may not be

able to receive any data from its NT MR-BS and NT-RSs when it is located within the overlapping area of their signal coverages.



Summary

In this chapter, we conceptually introduce the IEEE 802.16(j) network and present the steps required to configure a network case of this new network type over NCTUns. In addition, several useful commands and important dialog boxes for this type of network are also explained.