EXata 5.1
Wireless Model Library

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SCALABLE Network Technologies, Inc.

600 Corporate Pointe, Suite 1200
Culver City, CA 90230

+1.310.338.3318 TEL
+1.310.338.7213 FAX

SCALABLE-NETWORKS.COM

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600 Corporate Pointe, Suit 1200

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1 Overview of Model Library

1.1 List of Models in the Library

The models described in the Wireless Model Library are listed in Table 1-1.

TABLE 1-1. Wireless Library Models

Model Name	Model Type	Section Number
802.11 MAC Protocol	MAC Layer	Section 4.1
802.11a/g PHY Model	Physical Layer	Section 3.1
802.11b PHY Model	Physical Layer	Section 3.2
802.11n PHY Model	Physical Layer	Section 3.3
802.11e MAC Protocol	MAC Layer	Section 4.2
802.11n MAC Protocol	MAC Layer	Section 4.3
802.11s MAC Protocol	MAC Layer	Section 4.4
Abstract Network Equation - Satellite (ANESAT) Model	MAC Layer	Section 4.5
Abstract PHY Model	Physical Layer	Section 3.4
Ad-Hoc On Demand Distance Vector (AODV) Routing Protocol	Routing Protocol	Section 5.1
Aloha MAC Protocol	MAC Layer	Section 4.6
Aloha Satellite Model with RSV Support (Satellite-RSV)	Multi-layer	Section 7.1
Antenna Models	Physical Layer	Section 3.5
Battery Models	Miscellaneous	Section 10.1
Bit Error Rate-based (BER) Reception Model	Physical Layer	Section 3.6
Bordercast Resolution Protocol (BRP)	Routing Protocol	Section 5.2
Carrier Sense Multiple Access (CSMA) MAC Protocol	MAC Layer	Section 4.7
Cartesian Terrain Format	Terrain	Section 9.1
Constant Shadowing Model	Propagation	Section 2.1
Digital Elevation Model (DEM) Terrain Format	Terrain	Section 9.2
Digital Terrain Elevation (DTED) Terrain Format	Terrain	Section 9.3
Dynamic MANET On-demand (DYMO) Routing Protocol	Routing Protocol	Section 5.3

TABLE 1-1. Wireless Library Models (Continued)

Model Name	Model Type	Section Number
Dynamic Source Routing (DSR) Protocol	Routing Protocol	Section 5.4
ESRI Shapefile Terrain Format	Terrain	Section 9.4.5
Fast Rayleigh Fading Model	Propagation	Section 2.2
File-based Mobility Model	Mobility	Section 8.1
Fisheye State Routing Protocol	Routing Protocol	Section 5.5
Free-space Pathloss Model	Propagation	Section 2.3
Generic MAC Protocol	MAC Layer	Section 4.8
Group Node Placement and Mobility Models	Mobility	Section 8.2
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Interzone Routing Protocol (IERP)	Routing Protocol	Section 5.7
Intrazone Routing Protocol (IARP)	Routing Protocol	Section 5.6
Irregular Terrain Model (ITM)	Propagation	Section 2.5
Landmark Ad Hoc Routing (LANMAR) Protocol	Routing Protocol	Section 5.8
Location-Aided Routing (LAR) Protocol	Routing Protocol	Section 5.9
Lognormal Shadowing Model	Propagation	Section 2.6
Microwave Links	MAC Layer	Section 4.9
Multiple Access Collision Avoidance (MACA) MAC Protocol	MAC Layer	Section 4.10
On-Demand Multicast Routing Protocol (ODMRP)	Routing Protocol	Section 6.1
Optimized Link State Routing Protocol - INRIA (OLSR-INRIA)	Routing Protocol	Section 5.10
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Pathloss Matrix Model	Propagation	Section 2.7
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Random Waypoint Mobility Model	Mobility	Section 8.3
Rayleigh Fading Model	Propagation	Section 2.8
Ricean Fading Model	Propagation	Section 2.9
SNR-based Reception Model	Physical Layer	Section 3.8
Source Tree Adaptive Routing (STAR) Protocol	Routing Protocol	Section 5.12
Time Division Multiple Access (TDMA) MAC Protocol	MAC Layer	Section 4.11
Two-ray Pathloss Model	Propagation	Section 2.10
Urban Terrain Data Format	Terrain	Section 9.5
Weather Pattern Model	Miscellaneous	Section 10.2
Zone Routing Protocol (ZRP)	Routing Protocol	Section 5.13

1.2 Conventions Used

1.2.1 Format for Command Line Configuration

This section describes the general format for specifying parameters in input files, the precedence rules for parameters, and the conventions used in the description of command line configuration for each model.

1.2.1.1 General Format of Parameter Declaration

The general format for specifying a parameter in an input file is:

```
[<Qualifier>] <Parameter Name> [<Index>] <Parameter Value>
```

where

`<Qualifier>` The qualifier is optional and defines the scope of the parameter declaration. The scope can be one of the following: Global, Node, Subnet, and Interface. Multiple instances of a parameter with different qualifiers can be included in an input file. Precedence rules (see Section 1.2.1.2) determine the parameter value for a node or interface.

Global: The parameter declaration is applicable to the entire scenario (to all nodes and interfaces), subject to precedence rules. The scope of a parameter declaration is global if the qualifier is not included in the declaration.

Example:

```
MAC-PROTOCOL             MACDOT11
```

Node: The parameter declaration is applicable to specified nodes, subject to precedence rules. The qualifier for a node-level declaration is a list of space-separated node IDs or a range of node IDs (specified by using the keyword `thru`) enclosed in square brackets.

Example:

```
[5 thru 10] MAC-PROTOCOL            MACDOT11
```

Subnet: The parameter declaration is applicable to all interfaces in specified subnets, subject to precedence rules. The qualifier for a subnet-level declaration is a space-separated list of subnet addresses enclosed in square brackets. A subnet address can be specified in the IP dot notation or in the EXata N syntax.

Example:

```
[N8-1.0 N2-1.0] MAC-PROTOCOL       MACDOT11
```

Interface: The parameter declaration is applicable to specified interfaces. The qualifier for an interface-level declaration is a space-separated list of subnet addresses enclosed in square brackets.

Example:

```
[192.168.2.1 192.168.2.4] MAC-PROTOCOL MACDOT11
```

`<Parameter Name>`	Name of the parameter.
`<Index>`	Instance of the parameter to which this parameter declaration is applicable, enclosed in square brackets. This should be in the range 0 to *n* -1, where *n* is the number of instances of the parameter. The instance specification is optional in a parameter declaration. If an instance is not included, then the parameter declaration is applicable to all instances of the parameter, unless otherwise specified.
`<Parameter Value>`	Value of the parameter.

Note: There should not be any spaces between the parameter name and the index.

Examples of parameter declarations in input files are:

```
PHY-MODEL                                          PHY802.11b
[1] PHY-MODEL                                      PHY802.11a
[N8-1.0] PHY-RX-MODEL                              BER-BASED
[8 thru 10] ROUTING-PROTOCOL                       RIP
[192.168.2.1 192.168.2.4] MAC-PROTOCOL             GENERICMAC
NODE-POSITION-FILE                                 ./default.nodes
PROPAGATION-CHANNEL-FREQUENCY[0]                   2.4e9
[1 2] QUEUE-WEIGHT[1]                              0.3
```

Note: In the rest of this document, we will not use the qualifier or the index in a parameter's description. Users should use a qualifier and/or index to restrict the scope of a parameter, as appropriate.

1.2.1.2 Rules of Precedence

Parameters without Instances

If the parameter declarations do not include instances, then the following rules of precedence apply when determining the parameter values for specific nodes and interfaces:

Interface > Subnet > Node > Global

This can be interpreted as follows:

- The value specified for an interface takes precedence over the value specified for a subnet, if any.
- The value specified for a subnet takes precedence over the value specified for a node, if any.
- The value specified for a node takes precedence over the value specified for the scenario (global value), if any.

Parameters with Instances

If the parameter declarations are a combination of declarations with and without instances, then the following precedence rules apply (unless otherwise stated):

Interface[i] > Subnet[i] > Node[i] > Global[i] > Interface > Subnet > Node > Global

This can be interpreted as follows:

- Values specified for a specific instance (at the interface, subnet, node, or global level) take precedence over values specified without the instance.

- For values specified for the same instance at different levels, the following precedence rules apply:
  - The value specified for an interface takes precedence over the value specified for a subnet, if any, if both declarations are for the same instance.
  - The value specified for a subnet takes precedence over the value specified for a node, if any, if both declarations are for the same instance.
  - The value specified for a node takes precedence over the value specified for the scenario (global value), if any, if both declarations are for the same instance.

1.2.1.3 Parameter Description Format

In the Model Library, most parameters are described using a tabular format described below. The parameter description tables have three columns labeled “Parameter”, “Values”, and “Description”. Table 1-2 shows the format of parameter tables. Table 1-4 shows examples of parameter descriptions in this format.

TABLE 1-2. Parameter Table Format

Parameter	Values	Description
<Parameter Name> <Designation> <Scope> [<Instances>]	<Type> [<Range>] [<Default Value>] [<Unit>]	<Description>

Parameter Column

The first column contains the following entries:

- ***<Parameter Name>*:** The first entry is the parameter name (this is the exact name of the parameter to be used in the input files).

- ***<Designation>:*** This entry can be *Optional* or *Required*. These terms are explained below.
  - ***Optional***: This indicates that the parameter is optional and may be omitted from the configuration file. (If applicable, the default value for this parameter is included in the second column.)
  - ***Required***: This indicates that the parameter is mandatory and must be included in the configuration file.

- ***<Scope>:*** This entry specifies the possible scope of the parameter, i.e., if the parameter can be specified at the global, node, subnet, or interface levels. Any combination of these levels is possible.If the parameter can be specified at all four levels, the keyword “All” is used to indicate that.

  Examples of scope specification are:

  Scope: All

  Scope: Subnet, Interface

  Scope: Global, Node

- ***<Instances>:*** If the parameter can have multiple instances, this entry indicates the type of index. If the parameter can not have multiple instances, then this entry is omitted.

Examples of instance specification are:

Instances: channel number

Instances: interface index

Instances: queue index

Values Column

The second column contains the following information:

- ***<Type>*:** The first entry is the parameter type and can be one of the following: Integer, Real, String, Time, Filename, IP Address, Coordinates, Node-list, or List. If the type is a List, then all possible values in the list are enumerated below the word “List”. (In some cases, the values are listed in a separate table and a reference to that table is included in place of the enumeration.)

  Table 1-3 shows the values a parameter can take for each type.

TABLE 1-3. Parameter Types

Type	Description
Integer	Integer value Examples: `2`, `10`
Real	Real value Examples: `15.0`, `-23.5`, `2.0e9`
String	String value Examples: `TEST`, `SWITCH1`
Time	Time value expressed in EXata time syntax (refer to *EXata User’s Guide*) Examples: `1.5S`, `200MS`, `10US`

Filename	Name of a file in EXata filename syntax (refer to *EXata User’s Guide*)
	Examples:
	`../../data/terrain/los-angeles-w`
	(For Windows and UNIX)
	`C:\scalable\exata\5.1\scenarios\WF\WF.nodes`
	(For Windows)
	`/root/scalable/exata/5.1/scenarios/WF/WF.nodes`
	(For UNIX)

Path	Path to a directory in EXata path syntax (refer to *EXata User’s Guide*)
	Examples:
	`../../data/terrain` (For Windows and UNIX)
	`C:\scalable\exata\5.1\scenarios\default`
	(For Windows)
	`/root/scalable/exata/5.1/scenarios/default`
	(For UNIX)

IP Address	IPv4 or IPv6 address Examples: `192.168.2.1`, `2000:0:0:0::1`

TABLE 1-3. Parameter Types (Continued)

Type	Description
IPv4 Address	IPv4 address Examples: `192.168.2.1`
IPv6 Address	IPv6 address Examples: `2000:0:0:0::1`
Coordinates	Coordinates in Cartesian or Lat-Lon-Alt system. The altitude is optional. Examples: `(100, 200, 2.5)`, `(-25.3478, 25.28976)`
Node-list	List of node IDs separated by commas and enclosed in "`{`" and "`}`". Examples: `{2, 5, 10}`, `{1, 3 thru 6}`
List	One of the enumerated values. Example: See the parameter `MOBILITY` in Table 1-4.

Note: If the parameter type is List, then options for the parameter available in EXata Developer and the commonly used model libraries are enumerated. Additional options for the parameter may be available if some other model libraries or addons are installed. These additional options are not listed in this document but are described in the corresponding model library or addon documentation.

- ***<Range>*:** This is an optional entry and is used if the range of values that a parameter can take is restricted. The permissible range is listed after the label "*Range:*" The range can be specified by giving the minimum value, the maximum value, or both. If the range of values is not restricted, then this entry is omitted.

  If both the minimum and maximum values are specified, then the following convention is used to indicate whether the minimum and maximum values are included in the range:

`(min, max)`	`min` < parameter value < `max`
`[min, max)`	`min` ≤ parameter value < `max`
`(min, max]`	`min` < parameter value ≤ `max`
`[min, max]`	`min` ≤ parameter value ≤ `max`

`min` (or `max`) can be a parameter name, in which case it denotes the value of that parameter.

Examples of range specification are:

Range: ≥ `0`

Range: `(0.0, 1.0]`

Range: `[1, MAX-COUNT]`

Range: `[1S, 200S]`

Note: If an upper limit is not specified in the range, then the maximum value that the parameter can take is the largest value of the type (integer, real, time) that can be stored in the system.

- ***<Default>*:** This is an optional entry which specifies the default value of an optional or conditional-optional parameter. The default value is listed after the label "*Default:*"
- ***<Unit>*:** This is an optional entry which specifies the unit for the parameter, if applicable. The unit is listed after the label "*Unit:*". Examples of units are: meters, dBm, slots.

Description Column

The third column contains a description of the parameter. The significance of different parameter values is explained here, where applicable. In some cases, references to notes, other tables, sections in the User's Guide, or to other model libraries may be included here.

Table 1-4 shows examples of parameter descriptions using the format described above.

TABLE 1-4. Example Parameter Table

Parameter	Values	Description
`MOBILITY` Optional *Scope:* Global, Node	List: • `NONE` • `FILE` • `GROUP-MOBILITY` • `RANDOM-WAYPOINT` Default: `NONE`	Mobility model used for the node. If `MOBILITY` is set to `NONE`, then the nodes remain fixed in one place for the duration of the simulation. See Table 7-11 for a description of mobility models.
`BACKOFF-LIMIT` Required *Scope:* Subnet, Interface	Integer *Range:* `[4,10)` *Unit:* slots	Upper limit of backoff interval after collision. A backoff interval is randomly chosen between 1 and this number following a collision.
`IP-QUEUE-PRIORITY-QUEUE-SIZE` Required *Scope:* All *Instances:* queue index	Integer *Range:* `[1, 65535]` *Unit:* bytes	Size of the output priority queue.
`MAC-DOT11-DIRECTIONAL-ANTENNA-MODE` Optional *Scope:* All	List • `YES` • `NO` *Default:* `NO`	Indicates whether the radio is to use a directional antenna for transmission and reception.

1.2.2 Format for GUI Configuration

The GUI configuration section for a model outlines the steps to configure the model using the GUI. The following conventions are used in the GUI configuration sections:

Path to a Parameter Group

As a shorthand, the location of a parameter group in a properties editor is represented as a path consisting of the name of the properties editor, name of the tab within the properties editor, name of the parameter group within the tab (if applicable), name of the parameter sub-group (if applicable), and so on.

Example

The following statement:

Go to **Default Device Properties Editor > Interfaces > Interface # > MAC Layer**

is equivalent to the following sequence of steps:

1. Open the Default Device Properties Editor for the node.
2. Click the **Interfaces** tab.
3. Expand the applicable Interface group.
4. Click the **MAC Layer** parameter group.

The above path is shown in Figure 1-1.

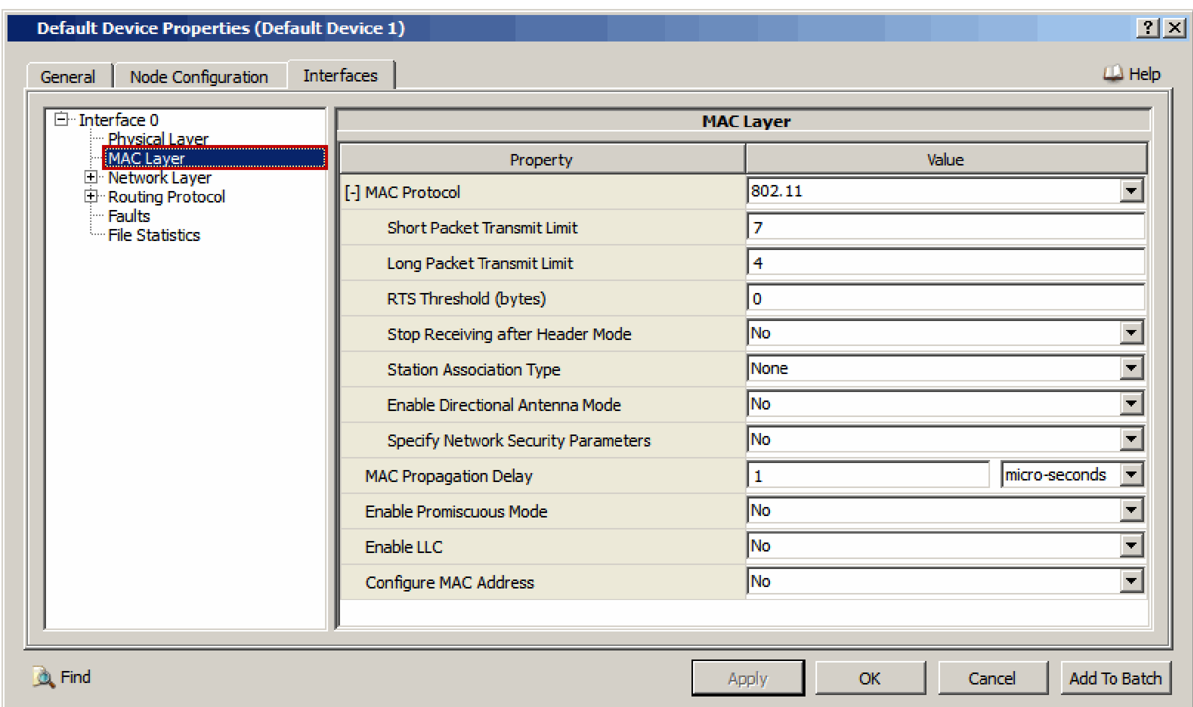

FIGURE 1-1. Path to a Parameter Group

Path to a Specific Parameter

As a shorthand, the location of a specific parameter within a parameter group is represented as a path consisting of all ancestor parameters and their corresponding values starting from the top-level parameter. The value of an ancestor parameter is enclosed in square brackets after the parameter name.

Example

The following statement:

Set **MAC Protocol** *[= 802.11]* **> Station Association Type** *[= Dynamic]* **> Set Access Point** *[= Yes]* **>** *Enable Power Save Mode* to *Yes*

is equivalent to the following sequence of steps:

1.Set **MAC Protocol** to *802.11*.

2.Set **Station Association Type** to *Dynamic.*

3.Set **Set Access Point** to *Yes*.

4.Set **Enable Power Save Mode** to *Yes*.

The above path is shown in Figure 1-2.

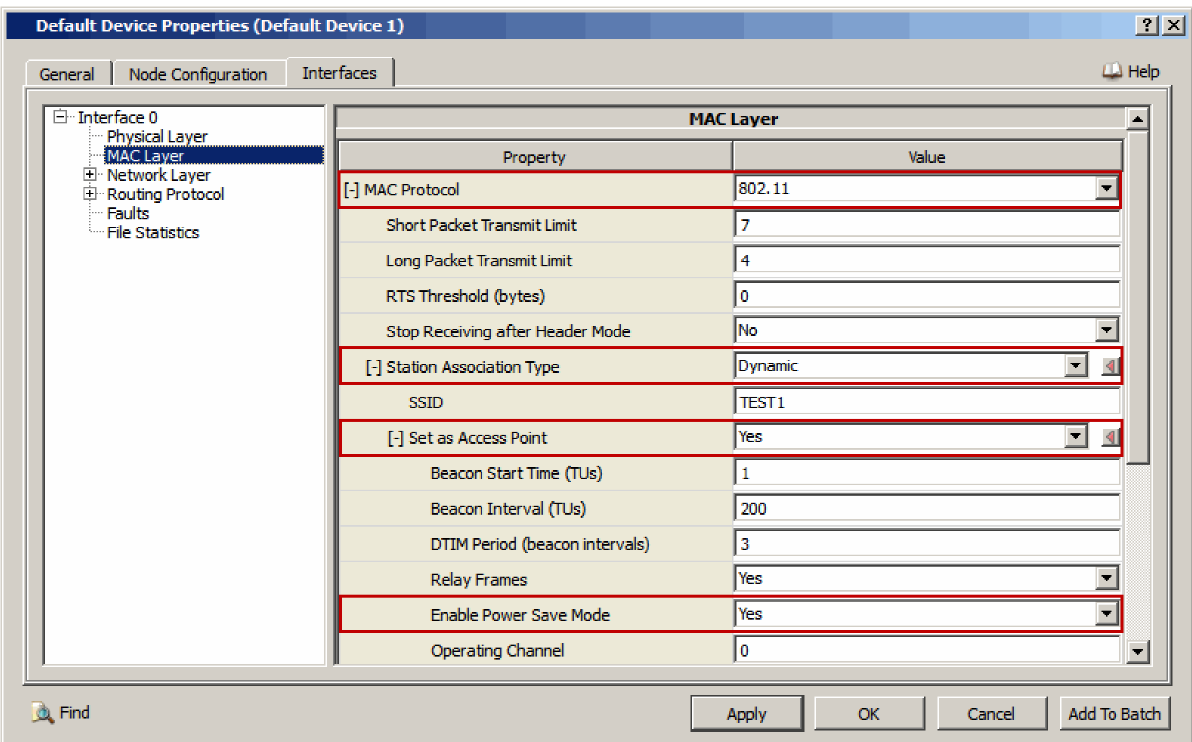

FIGURE 1-2. Path to a Specific Parameter

Parameter Table

GUI configuration of a model is described as a series of a steps. Each step describes how to configure one or more parameters. Since the GUI display name of a parameter may be different from the name in the configuration file, each step also includes a table that shows the mapping between the GUI names and command line names of parameters configured in that step. For a description of a GUI parameter, see the description of the equivalent command line parameter in the command line configuration section.

The format of a parameter mapping table is shown in Table 1-5.

TABLE 1-5. Mapping Table

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
<GUI Display Name>	<Scope>	*<Command Line Parameter Name>*

The first column, labeled "GUI Parameter", lists the name of the parameter as it is displayed in the GUI.

The second column, labeled "Scope of GUI Parameter", lists the level(s) at which the parameter can be configured. *<Scope>* can be any combination of: Global, Node, Subnet, Wired Subnet, Wireless Subnet, Point-to-point Link, and Interface.

Table 1-6 lists the Properties Editors where parameters with different scopes can be set.

Notes: **1.** Unless otherwise stated, the "Subnet" scope refers to "Wireless Subnet".

2. The scope column can also refer to Properties Editors for special devices and network components (such as ATM Device Properties Editor) which are not included in Table 1-6.

TABLE 1-6. Properties Editors for Different Scopes

Scope of GUI Parameter	Properties Editor
Global	Scenario Properties Editor
Node	Default Device Properties Editor (General and Node Configuration tabs)
Subnet Wireless Subnet	Wireless Subnet Properties Editor
Wired Subnet	Wired Subnet Properties Editor
Point-to-point Link	Point-to-point Link Properties Editor
Interface	Interface Properties Editor, Default Device Properties Editor (Interfaces tab)

The third column, labeled "Command Line Parameter", lists the equivalent command line parameter.

Note: For some parameters, the scope may be different in command line and GUI configurations (a parameter may be configurable at fewer levels in the GUI than in the command line).

Table 1-7 is an example of a parameter mapping table.

TABLE 1-7. Example Mapping Table

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Define Area	Node	`OSPFv2-DEFINE-AREA`
OSPFv2 Configuration File	Node	`OSPFv2-CONFIG-FILE`
Specify Autonomous System	Node	N/A
Configure as Autonomous System Boundary Router	Node	`AS-BOUNDARY-ROUTER`
Inject External Route	Node	N/A
Enable Stagger Start	Node	`OSPFv2-STAGGER-START`

2 Propagation Models

This chapter describes features, configuration requirements and parameters, statistics, and scenarios for Propagation Models, and consists of the following sections:

- Constant Shadowing Model
- Fast Rayleigh Fading Model
- Free-space Pathloss Model
- Inter-channel Interference Model
- Irregular Terrain Model (ITM)
- Lognormal Shadowing Model
- Pathloss Matrix Model
- Rayleigh Fading Model
- Ricean Fading Model
- Two-ray Pathloss Model

2.1 Constant Shadowing Model

2.1.1 Description

A shadowing model is used to represent the signal attenuation caused by obstructions along the propagation path. The constant shadowing model is suitable for the scenarios without mobility where the obstructions along the propagation paths remain unchanged.

2.1.2 Command Line Configuration

To select the Constant Shadowing model, include the following parameter in the scenario configuration (.config) file:

```
PROPAGATION-SHADOWING-MODEL[<Index>]        CONSTANT
```

where

`<Index>`	Channel index to which this parameter declaration is applicable, enclosed in square brackets. This should be in the range 0 to *n* -1, where *n* is the number of channels. The index specification is optional. If an index is not included, then the parameter declaration is applicable to all channels.

Constant Shadowing Parameters

Table 2-1 shows the Constant Shadowing model parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 2-1. Constant Shadowing Parameters

Parameter Name	Value	Description
`PROPAGATION-SHADOWING-MEAN` *Optional* *Scope:* Global *Instances:* channel index	Real *Range:* ≥ `0` *Default:* `4.0` *Unit:* dB	Specifies propagation shadowing mean (most likely shadowing value for the propagation environment). The more the number of obstructions along the propagation path, the higher this value should be.

2.1.3 GUI Configuration

To configure the Constant Shadowing model parameters, perform the following steps:

1. Go to **Scenario Properties Editor > Channel Properties**.
2. Set **Number of Channels** to the desired value as shown in Figure 2-1.

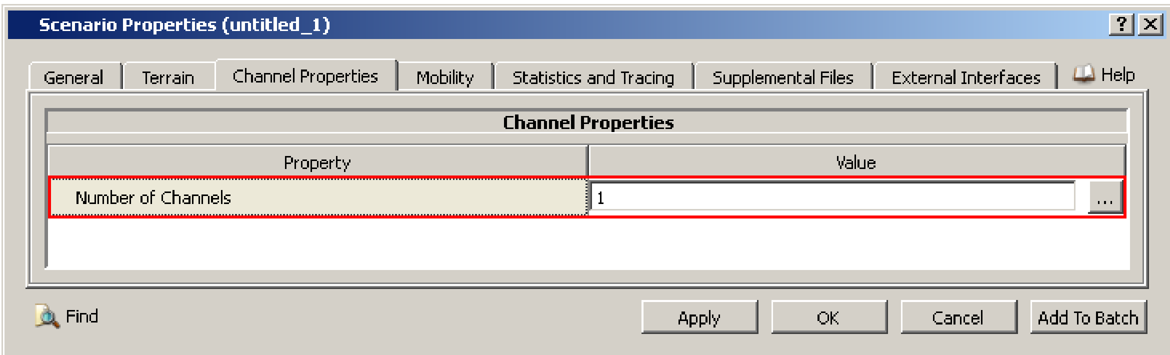

FIGURE 2-1. Setting Number of Channels

3. Click on the **Open Array Editor** ... button in the **Value** column. This opens the Array Editor.
4. In the left panel of the Array Editor, select the index of the channel to be configured. In the right panel, set **Shadowing Model** to *Constant* and set the dependent parameters as shown in Table 2-2.

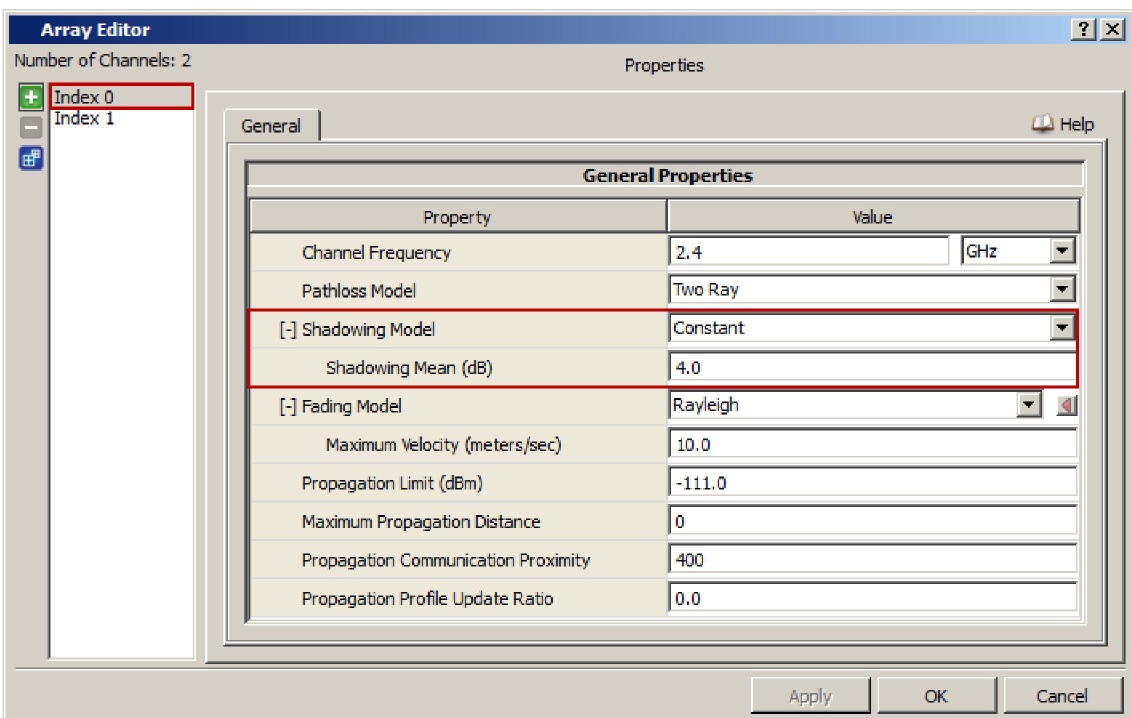

FIGURE 2-2. Setting Constant Shadowing Model Parameters

TABLE 2-2. Command Line Equivalent of Constant Shadowing Model Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Shadowing Mean	Global	`PROPAGATION-SHADOWING-MEAN`

2.1.4 Statistics

There are no statistics collected by the Constant Shadowing model.

2.2 Fast Rayleigh Fading Model

2.2.1 Description

The Fast Rayleigh fading model is a statistical model to represent the fast variation of signal amplitude at the receiver due to the motion of the transmitter/receiver pair.

In wireless propagation, the motion of the transmitter/receiver or the surrounding objects causes Doppler frequency shift in the received signal components, which causes the fast variation of the received signal amplitude. The variation in the received signal amplitude is affected by the speeds and relative directions of the receiver and transmitter.

EXata's Fast Rayleigh fading model uses the instantaneous relative speed between the transmitter and receiver and a pre-computed time series data sequence to represent the fast variation of the received signal amplitude.

2.2.2 Command Line Configuration

To select the Fast Rayleigh fading model, include the following parameter in the scenario configuration (.config) file:

```
PROPAGATION-FADING-MODEL[<Index>]        FAST-RAYLEIGH
```

where

`<Index>`	Channel index to which this parameter declaration is applicable, enclosed in square brackets. This should be in the range 0 to *n* -1, where *n* is the number of priority channels. The index specification is optional. If an index is not included, then the parameter declaration is applicable to all channels.

Fast Rayleigh Fading Model Parameters

Table 2-3 describes the Fast Rayleigh fading model parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 2-3. Fast Rayleigh Fading Model Parameters

Parameter	Value	Description
PROPAGATION-FADING-GAUSSIAN-COMPONENTS-FILE *Required* *Scope:* Global	Filename	Specifies the name of the file that stores the series of Gaussian components. The format of this file is described in Section 2.2.2.1.

2.2.2.1 Format of the Gaussian Components File

The first three lines of the Gaussian components file (.fading) specify the sampling rate, base doppler frequency, and the number of Gaussian components. The first three lines have the following format:

```
SAMPLING-RATE                    <sampling rate>
BASE-DOPPLER-FREQUENCY           <base Doppler frequency>
NUMBER-OF-GAUSSIAN-COMPONENTS    <num Gaussian components>
```

where

`<sampling rate>`	: Sampling rate, in Hz.
`<base Doppler frequency>`	: Base Doppler frequency, in Hz.
`<num Gaussian components>`	: Number of Gaussian components in the file.

These lines are followed by `<num Gaussian components>` lines, each in the following format:

```
<Gaussian component 1>  <Gaussian component 2>
```

where

`<Gaussian component 1>`	: First Gaussian component.
`<Gaussian component 2>`	: Second Gaussian component.

A default Gaussian compounds file, default.fading, can be found in EXATA_HOME/scenarios/default. A segment of this file is shown below.

```
SAMPLING-RATE 1000
BASE-DOPPLER-FREQUENCY 30.0
NUMBER-OF-GAUSSIAN-COMPONENTS 16384

-5.6482112e-001 -1.2675110e+000
-5.7047958e-001 -1.0847877e+000
-5.6146223e-001 -8.8065119e-001
-5.4280320e-001 -6.6004259e-001
-5.1605105e-001 -4.2597880e-001
-4.7640535e-001 -1.8909923e-001
...
```

2.2.3 GUI Configuration

To configure the Fast Rayleigh Fading Model parameters, perform the following steps:

1. Go to **Scenario Properties Editor > Channel Properties**.
2. Set **Number of Channels** to the desired value as shown in Figure 2-3.

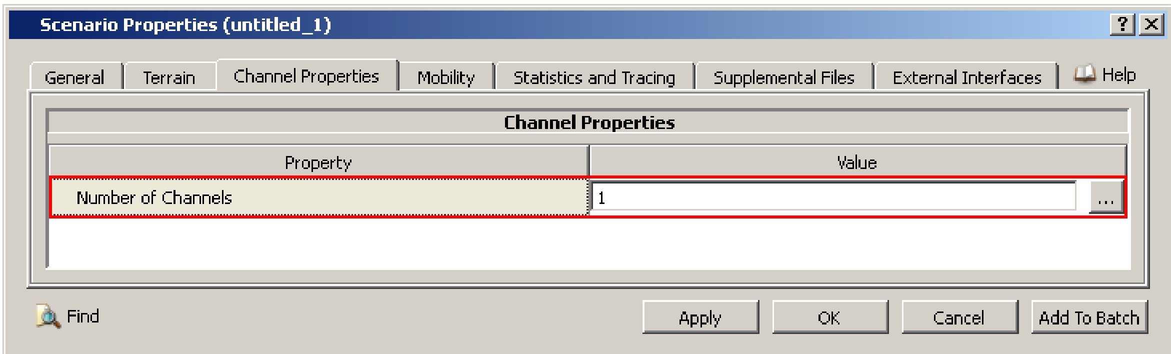

FIGURE 2-3. Setting Number of Channels

3. Click on the **Open Array Editor** ... button in the **Value** column. This opens the Array Editor.
4. In the left panel of the Array Editor, select the index of the channel to be configured. In the right panel, set **Fading Model** to *Fast Rayleigh.* Click **OK** to close the Array Editor.

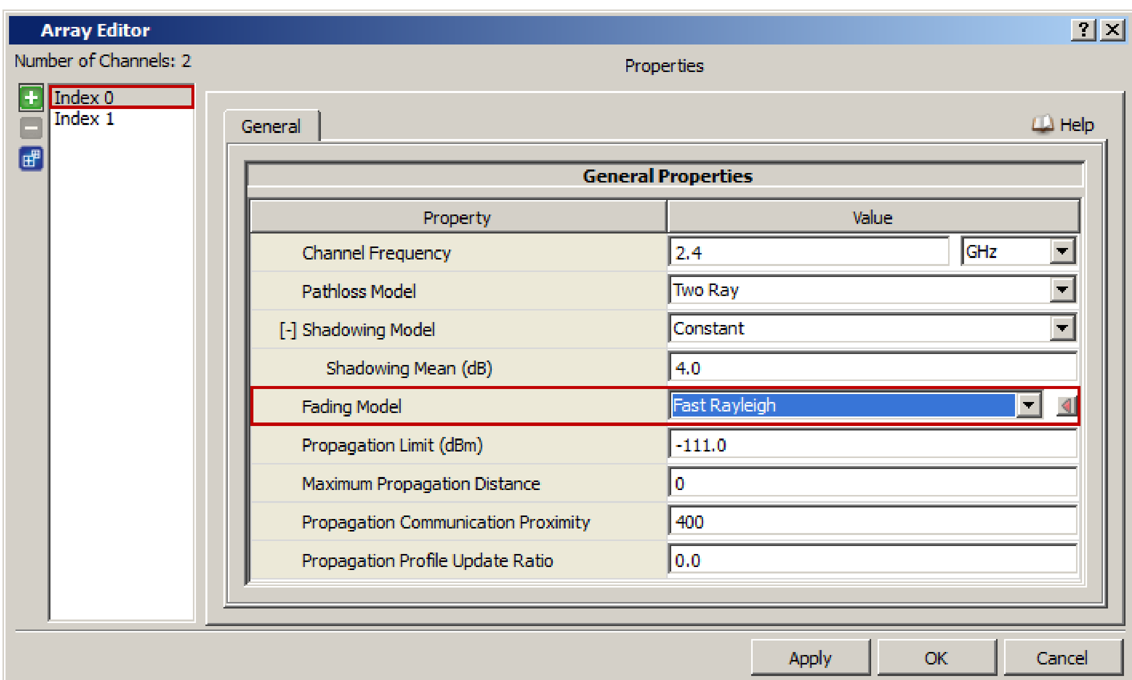

FIGURE 2-4. Setting Fast Rayleigh Parameters

5. In the Scenario Properties Editor, specify the name of the Gaussian components file.

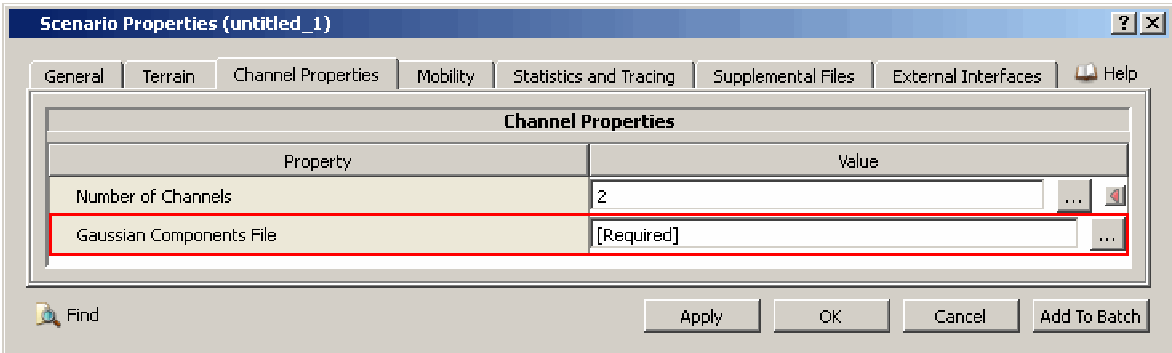

FIGURE 2-5. Setting Gaussian Components File

TABLE 2-4. Command Line Equivalent of Gaussian Components

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Gaussian Components File	Global	PROPAGATION-FADING-GAUSSIAN-COMPONENTS-FILE

2.2.4 Statistics

There are no statistics collected for the Fast Rayleigh fading model.

2.3 Free-space Pathloss Model

2.3.1 Description

The Free-space Pathloss model assumes an omni-directional line-of-sight propagation path. The signal strength decays with the square of the distance between the transmitter and receiver.

2.3.2 Command Line Configuration

To select the Free-space Pathloss model, include the following parameter in the scenario configuration (.config) file:

```
PROPAGATION-PATHLOSS-MODEL[<Index>]        FREE-SPACE
```

where

`<Index>`	Channel index to which this parameter declaration is applicable, enclosed in square brackets. This should be in the range 0 to *n* -1, where *n* is the number of channels. The index specification is optional. If an index is not included, then the parameter declaration is applicable to all channels.

Freespace Pathloss Parameters

There are no additional configuration parameters for the Free-space pathloss models.

2.3.3 GUI Configuration

To configure the Free-Space Pathloss Model parameters, perform the following steps:

1. Go to **Scenario Properties Editor > Channel Properties**.
2. Set **Number of Channels** to the desired value as shown in Figure 2-6.

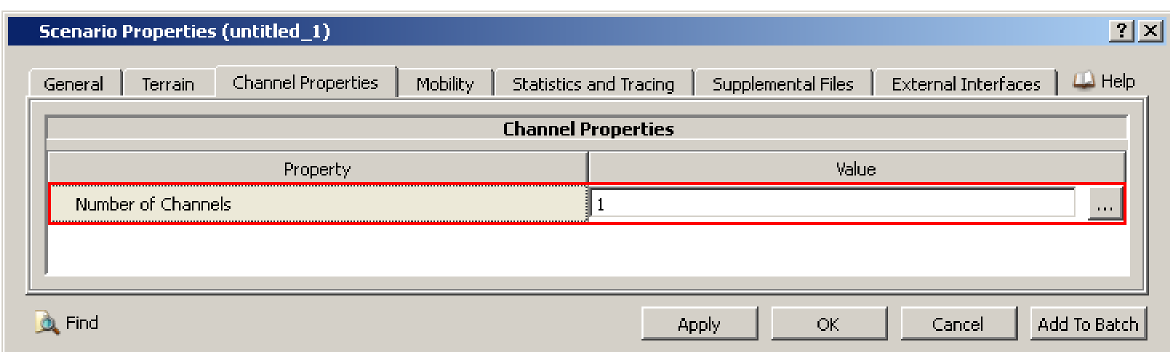

FIGURE 2-6. Setting Number of Channels

3. Click on the **Open Array Editor** ... button in the **Value** column. This opens the Array Editor.

4. In the left panel of the Array Editor, select the index of the channel to be configured. In the right panel, set **Pathloss Model** to *Free-Space*. There are no dependent parameters for this pathloss model.

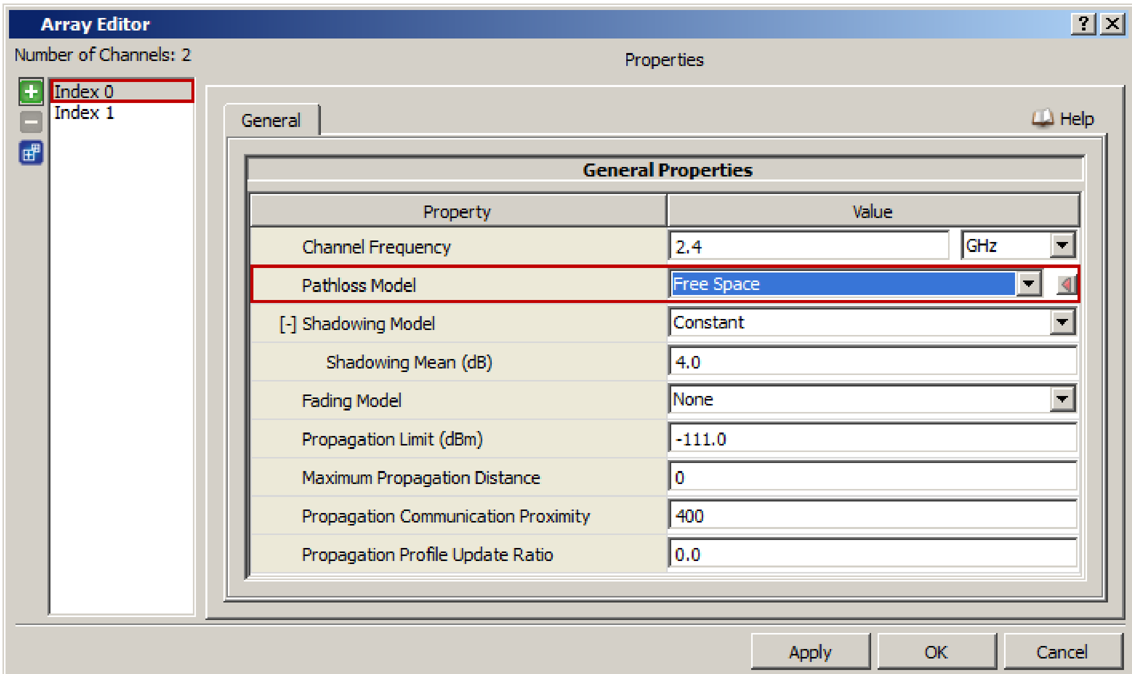

FIGURE 2-7. Setting Pathloss Model to Free-Space

2.3.4 Statistics

There are no statistics collected by the Free-space Pathloss model.

2.4 Inter-channel Interference Model

2.4.1 Description

The Inter-channel Interference model accounts for both co-channel and inter-channel interference. (If the Inter-channel Interference model is not enabled only co-channel interference is taken into account.)

Co-channel interference occurs when the transmitting node and receiving nodes work on the same channel, the same channel index, the same frequency, and the same bandwidth. Inter-channel interference occurs when the transmitting node and receiving nodes work on different channels, different channel indexes, different frequencies, or different bandwidths, and there is frequency overlap between the channels. The Inter-channel Interference model estimates the effect of wide band jamming, narrow band jamming, frequency hopping jamming, frequency hopping spectrum spreading, frequency planning, spectrum analysis and spectrum management, etc.

In the case of inter-channel interference, the model estimates the overlap bandwidth for the desired signal according to the frequencies and bandwidths for the desired and interference signals. The inter-channel interference power is estimated based on the overlap bandwidth, node's properties such as transmitter power and antenna gain, etc., and system parameters such as frequency, pathloss model, and distance, etc.

2.4.2 Features and Assumptions

This section describes the implemented features, assumptions, and limitations of the Inter-channel Interference model.

2.4.2.1 Implemented Features

- Estimation of channel interference, which includes both co-channel and inter-channel interference.
- Accurate estimation of overlap bandwidth for the inter-channel signals, taking into account the carrier frequency and bandwidth of the transmitting node and receiving node.
- Proper delivery of signals to nodes. The signals will not only be delivered to the node that works on the same channel as the transmitter, but also be delivered to the node that works on the adjacent channel, if there is frequency overlap between the transmitting channel and receiving channel and the signal is of sufficient strength.
- Estimation of the power spectrum density of the interference signal.

2.4.2.2 Assumptions and Limitations

- The in-band signal power spectrum is flat.
- There is no out-band power leak.
- The ideal rectangle filters are used at the transmitter and receiver.

2.4.3 Command Line Configuration

To enable the Inter-channel Interference model for a channel, include the following parameter in the scenario configuration (.config) file:

```
PROPAGATION-ENABLE-CHANNEL-OVERLAP-CHECK[<Index>] YES
```

where

`<Index>`	Channel index to which this parameter declaration is applicable, enclosed in square brackets. This should be in the range 0 to *n* -1, where *n* is the number of channels. The index specification is optional. If an index is not included, then the parameter declaration is applicable to all channels.

Note: The default value of the parameter `PROPAGATION-ENABLE-CHANNEL-OVERLAP-CHECK` is `NO`.

2.4.4 GUI Configuration

To configure the Inter-channel Interference model parameters in the GUI, do the following:

1. Go to **Scenarios Property Editor > Channel Properties**.
2. Set **Number of Channels** to the desired value as shown in Figure 2-8.

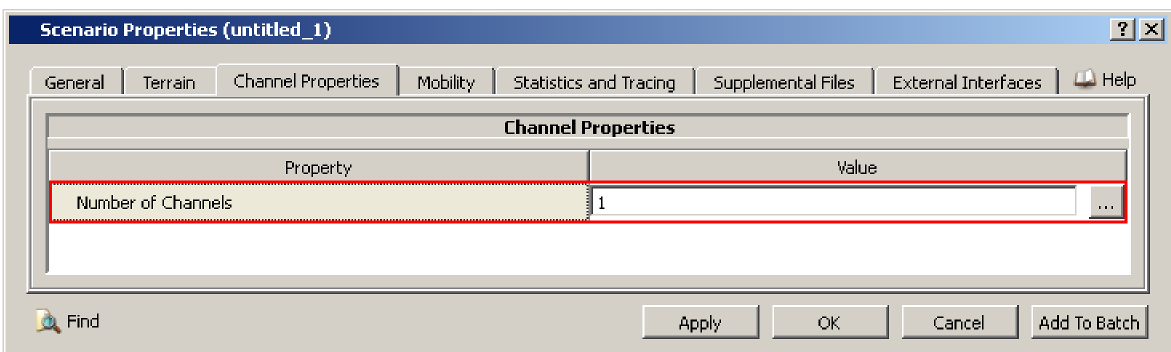

FIGURE 2-8. Setting Number of Channels

3. Click on the **Open Array Editor** ... button in the Value column. This opens the **Array Editor**.
4. In the left panel of the Array Editor, select the index of the channel to be configured.
   For each channel, set the parameter **Take Channel Interference into Account**.

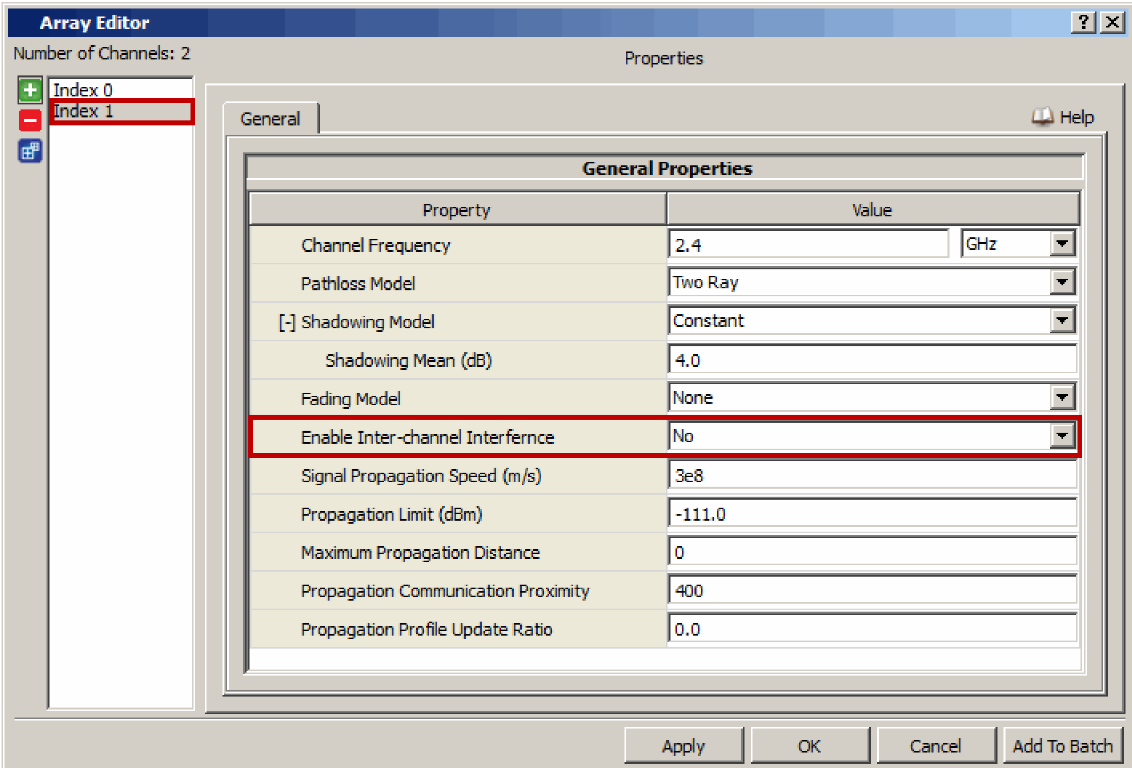

FIGURE 2-9. Enabling Inter-channel Interference Model

TABLE 2-5. Command Line Equivalent of Inter-channel Interference Model Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Enable Inter-channel Interference	Global	`PROPAGATION-ENABLE-CHANNEL-OVERLAP-CHECK`

2.4.5 Statistics

There are no statistics collected for the Inter-channel Interference model.

2.4.6 Scenarios Included in EXata

The EXata distribution includes sample scenarios for the Inter-channel Interference model. All scenarios are located in the directory EXATA_HOME\scenarios\inter-channel_interference. Table 2-6 lists the sub-directory where each scenario is located.

TABLE 2-6. Scenarios Included in EXata

Scenario Sub-directory	Description
Abstract_TwoChannel	To verify the Inter-channel Interference model with the PHY Abstract model. The scenario consists of two channels working on different frequencies.
Abstract_ThreeChannel	To verify the Inter-channel Interference model with the PHY Abstract model. The scenario consists of three channels working on different frequencies.
Dot11_TwoChannel	To verify the Inter-channel Interference model with the 802.11 PHY model. The scenario consists of two channels working on different frequencies.
Zigbee_TwoChannel	To verify the Inter-channel Interference model with the 802.15.4 PHY model. The scenario consists of two channels working on different frequencies.

2.5 Irregular Terrain Model (ITM)

2.5.1 Description

The Irregular Terrain Model (ITM) is a propagation model to estimate propagation attenuations for frequencies between 20 MHz and 20 GHz. It is an improved version of the Longley-Rice model, which is based on electromagnetic theory, statistical analyses of terrain features, and extensive sets of measurements. ITM works with a terrain profile. The median pathloss is predicted using the path geometry of the terrain profile along the propagation path and the refractivity of the troposphere. Other than terrain profile along the propagation path, parameters such as path length, frequency, effective antenna heights, surface refractivity, ground conductivity, ground dielectric constant, and climate are taken into account to calculate the propagation attenuation.

ITM is capable of accounting for the terrain effects on the propagation attenuation and provides more accurate results than free space and two ray propagation models.

2.5.2 Command Line Configuration

To specify ITM as the pathloss model, include the following parameter in the scenario configuration (.config) file:

```
PROPAGATION-PATHLOSS-MODEL[<Index>]          ITM
```

where

`<Index>`	Channel index to which this parameter declaration is applicable, enclosed in square brackets. This should be in the range 0 to *n* -1, where *n* is the number of channels. The index specification is optional. If an index is not included, then the parameter declaration is applicable to all channels.

Configuration Requirements

The ITM propagation model requires terrain data files. Currently DEM and DTED terrain data are supported. See Section 9.2 and Section 9.3 for details of specifying terrain data in DEM and DTED formats, respectively.

ITM Parameters

Table 2-7 lists the ITM parameters specified in the scenario configuration (.config) file. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 2-7. ITM Parameters

Parameter	Value	Description
`PROPAGATION-SAMPLING-DISTANCE` *Optional* *Scope:* Global *Instances:* channel index	Real *Range:* `> 0.0` *Default:* `100.0` *Unit:* meters	Specifies the sampling distance. For a given terrain profile along propagation path, the shorter the sampling distance, the more sample points for the terrain profile. It is recommended to set the parameters to the resolution of the terrain data, e.g., 100 meters for DTED level1.
`PROPAGATION-REFRACTIVITY` *Optional* *Scope:* Global *Instances:* channel index	Real *Range:* `> 0.0` *Default:* `360`	Specifies the refractivity value of the terrain. The recommended values for different terrain types are: Equatorial 360 Continental Subtropical 320 Maritime Tropical 370 Desert 280 Continental Temperate 301 Maritime Temperate, Over Land 320 Maritime Temperate, Over Sea 350
`PROPAGATION-CONDUCTIVITY` *Optional* *Scope:* Global *Instances:* channel index	Real *Range:* `> 0.0` *Default:* `0.005` *Unit:* siemens/ meter	Specifies the conductivity of the earth's surface. The recommended values for different terrain types are: Average Ground 0.005 Poor Ground 0.001 Good Ground 0.02 Fresh Water 0.01 Salt Water 5.0
`PROPAGATION-PERMITTIVITY` Optional *Scope:* Global *Instances:* channel index	Real *Range:* `[1.0, 100.0]` *Default:* `15.0` *Unit:* farads/meter	Specifies the relative permittivity of the earth's surface. The recommended values for different terrain types are: Average Ground 15 Poor Ground 4 Good Ground 25 Fresh Water 81 Salt Water 81
`PROPAGATION-HUMIDITY` *Optional* *Scope:* Global *Instances:* channel index	Real *Range:* `> 0.0` *Default:* `10.0`	Specifies the relative humidity at the transmitter site.

TABLE 2-7. ITM Parameters (Continued)

Parameter	Value	Description
`PROPAGATION-CLIMATE` *Optional* *Scope:* Global *Instances:* channel index	Integer *Range:* `[1, 7]` *Default:* `1`	Specifies the climate conditions. The integer values correspond to the following: 1 Equatorial 2 Continental Subtropical 3 Maritime Tropical 4 Desert 5 Continental Temperate 6 Maritime Temperate, Over Land 7 Maritime Temperate, Over Sea
`ANTENNA-POLARIZATION` *Optional* *Scope:* Global *Instances:* channel index	List: • `HORIZONTAL` • `VERTICAL` *Default:* `VERTICAL`	Specifies the direction of electromagnetic waves radiated by the antenna relative to the earth's surface.

2.5.3 GUI Configuration

This section describes how to configure Irregular Terrain Model in the GUI using the Scenario properties Editor.

To configure the Irregular Terrain Model parameters, perform the following steps:

1. Go to **Scenario Properties Editor > Channel Properties**.

2. Set **Number of Channels** to the desired value as shown in Figure 2-10.

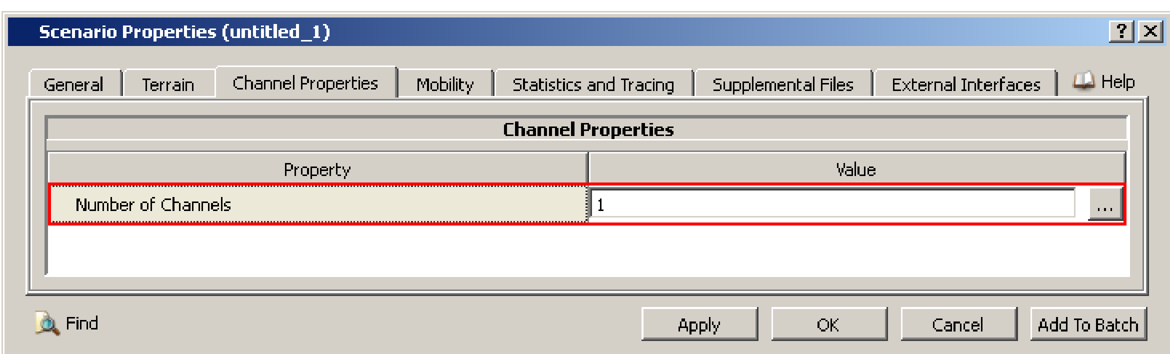

FIGURE 2-10. Setting Number of Channels

3. Click on the **Open Array Editor** ... button in the **Value** column. This opens the Array Editor.

4. In the left panel of the Array Editor, select the index of the channel to be configured. In the right panel, set **Pathloss Model** to *Irregular Terrain Model* and set the dependent parameters listed in Table 2-8.

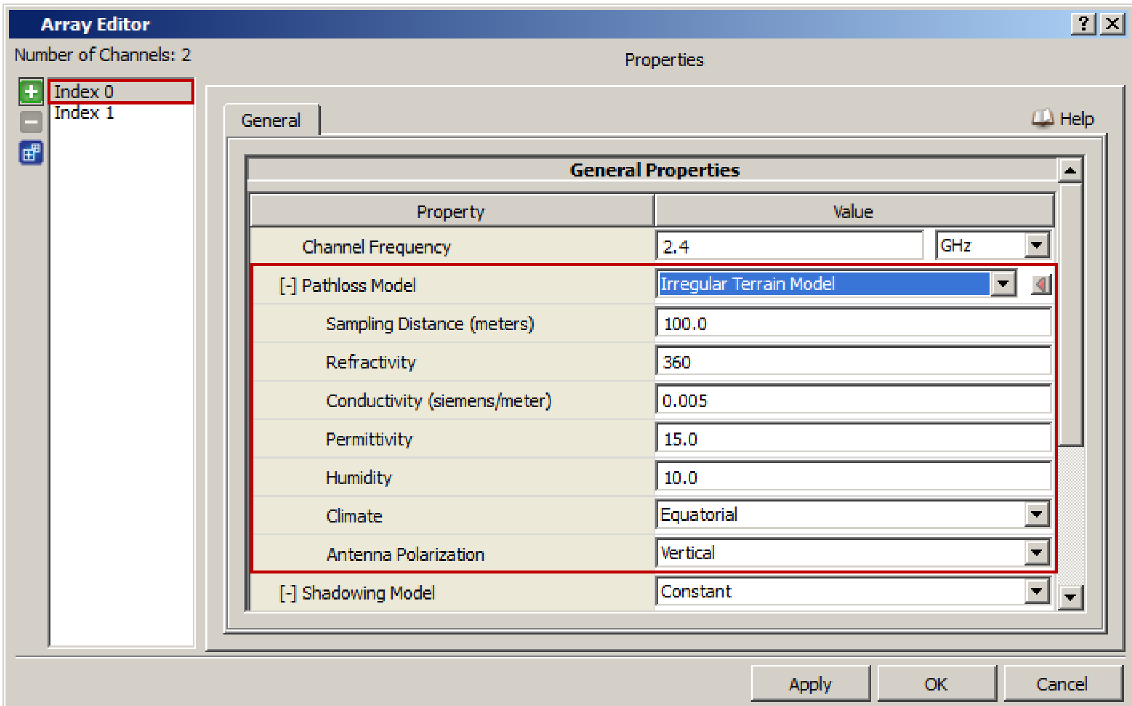

FIGURE 2-11. Setting Irregular Terrain Model Parameters

TABLE 2-8. Command Line Equivalent of Irregular Terrain Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Sampling Distance	Global	`PROPAGATION-SAMPLING-DISTANCE`
Refractivity	Global	`PROPAGATION-REFRACTIVITY`
Conductivity	Global	`PROPAGATION-CONDUCTIVITY`
Permittivity	Global	`PROPAGATION-PERMITTIVITY`
Humidity	Global	`PROPAGATION-HUMIDITY`
Climate	Global	`PROPAGATION-CLIMATE`
Antenna Polarization	Global	`ANTENNA-POLARIZATION`

Setting Parameters

- For **Climate**, select the distribution from the list (*Continental Subtropical, Continental Tropical, Desert, Equatorial, Maritime Temperate Over land, Maritime Temperate Over Sea,* or *Maritime Tropical*).
- For **Antenna Polarization**, select the distribution from the list (*Horizontal* or *Vertical*).

2.5.4 References

1. George Hufford “The ITS Irregular Terrain Model, version 1.2.2 Algorithm”. U.S. Department of Commerce NTIA/ITS Institute for Telecommunication Sciences Irregular Terrain Model (ITM) (Longley-Rice).

2.6 Lognormal Shadowing Model

2.6.1 Description

The Lognormal Shadowing model is suitable for a scenario with mobility and obstructions within the propagation environment. In this model, the shadowing value follows a log-normal distribution with a user-specified standard deviation. In general, this shadowing value should be in the range of 4 to 12 dB depending on the density of obstructions within the propagation environment.

2.6.2 Command Line Configuration

To select the Lognormal shadowing model, include the following parameter in the scenario configuration (.config) file:

```
PROPAGATION-SHADOWING-MODEL[<Index>]        LOGNORMAL
```

where

`<Index>`	Channel index to which this parameter declaration is applicable, enclosed in square brackets. This should be in the range 0 to *n* -1, where *n* is the number of channels. The index specification is optional. If an index is not included, then the parameter declaration is applicable to all channels.

Lognormal Shadowing Model Parameters

Table 2-9 describes the Lognormal shadowing model configuration parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 2-9. Lognormal Shadowing Model Parameters

Parameter Name	Value	Description
`PROPAGATION-SHADOWING-MEAN` *Optional* *Scope:* Global *Instances:* channel index	Real *Range:* ≥ `0` *Default:* `4.0` *Unit:* dB	Standard deviation of the log-normal distribution. The higher the density of obstructions within the propagation environment, the higher this value should be.

2.6.3 GUI Configuration

To configure the Lognormal Shadowing Model parameters, perform the following steps:

1. Go to **Scenario Properties Editor > Channel Properties**.
2. Set **Number of Channels** to the desired value as shown in Figure 2-12.

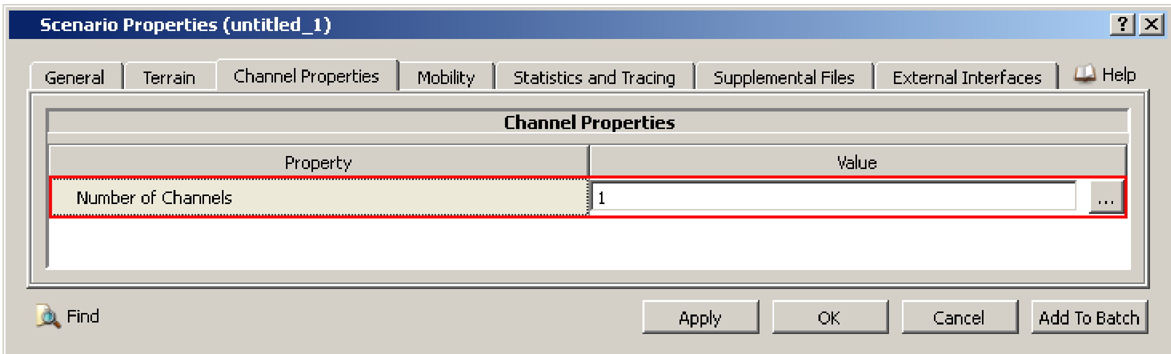

FIGURE 2-12. Setting Number of Channels

3. Click on the **Open Array Editor** ... button in the **Value** column. This opens the Array Editor.
4. In the left panel of the Array Editor, select the index of the channel to be configured. In the right panel, set **Shadowing Model** to *Lognormal* and set the dependent parameters listed in Table 2-10.

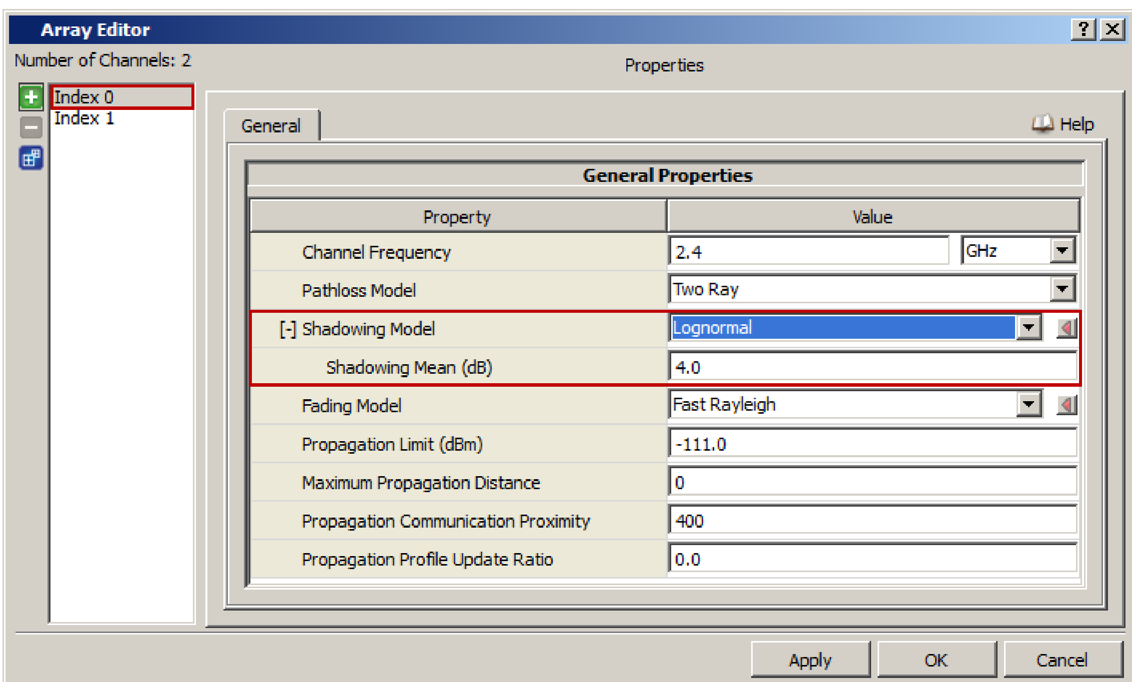

FIGURE 2-13. Setting Lognormal Parameters

TABLE 2-10. Command Line Equivalent of Lognormal Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Shadowing Mean	Global	`PROPAGATION-SHADOWING-MEAN`

2.6.4 Statistics

There are no statistics collected by the Lognormal shadowing model.

2.7 Pathloss Matrix Model

2.7.1 Description

This model uses a four-dimensional matrix indexed by source node, destination node, simulation time, and channel number. The matrix value for a (source, destination, simulation-time) is the pathloss value between the given source-destination pair at the given simulation time. The pathloss matrix is input as a text file.

2.7.2 Command Line Configuration

To select the Pathloss Matrix model, include the following parameter in the scenario configuration (.config) file:

```
PROPAGATION-PATHLOSS-MODEL[<Index>]    PATHLOSS-MATRIX
```

where

`<Index>` Channel index to which this parameter declaration is applicable, enclosed in square brackets. This should be in the range 0 to *n* -1, where *n* is the number of priority channels.

The index specification is optional. If an index is not included, then the parameter declaration is applicable to all channels.

Pathloss Matrix Model Parameters

Table 2-11 describes the Pathloss Matrix configuration parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 2-11. Pathloss Matrix Model Parameters

Parameter Name	Value	Description
PROPAGATION-PATHLOSS-MATRIX-FILE *Required* *Scope:* Global	Filename	Name of the file that contains the pathloss matrix. The format of the pathloss matrix file is described in Section 2.7.2.1.

2.7.2.1 Format of the Pathloss Matrix File

The first line in the pathloss matrix file lists the channel frequencies in use in the scenario and has the following format:

```
Freq:<Num-channels>:<Frequency 1>:<Frequency 2> ...:<Frequency n>
```

where

`<Num-channels>`	Number of channels. This must be the same as the number of channels specified in the configuration file.
`<Frequency i>`	Frequency of the *i*th channel, in GHz. There should be as many occurrences of this field as the number of channels in the scenario.

The second line specifies the number of nodes in the scenario and has the following format:

```
Nodes:<Num-nodes>
```

where

`<Num-nodes>`	Number of nodes in the scenario.

Each of the remaining lines gives the pathloss values between a pair of nodes for each of the channels at a specific simulation time. The format for these lines is:

```
<Time> <Node 1> <Node 2> <Pathloss 1> <Pathloss 2>... <Pathloss m>
```

where:

`<Time>`	Simulation time (in seconds). This is an integer or real value.
`<Node 1>`, `<Node 2>`	Node IDs.
`<Pathloss i>`	Pathloss (in dB) on the *i*th channel from `<Node 1>` to `<Node 2>` at the specified simulation time. There should be between 1 and *num-channels* occurrences of this field, where *num-channels* is the number of channels in the scenario.

Note: The lines specifying pathloss values can be in any order, i.e., they need not be ordered by simulation time or node IDs.

Rules for Determining Pathloss Values

The following rules determine the pathloss value between two nodes on a specific channel at a specific time. In the following, *num-channels* is the number of channels in the scenario.

1. If for any time t, there are m (1 ≤ m ≤ num-channels) pathloss values specified from node N1 to node N2, then these pathloss values are for the first m channels. If the i^{th} pathloss value is 1000, then N2 is not reachable from N1 on channel i at time t.

   If t_1 is the earliest time for which pathloss is specified from node N1 to node N2 and there are m pathloss values specified (1 ≤ m ≤ num-channels), then for channel i (m < i ≤ num-channels), N2 is assumed to be not reachable from N1 up to and including time t_1.

   For any subsequent time t_2 ($t_2 > t_1$), if there are p pathloss values specified from N1 to N2, then for channel i (p < i ≤ num-channels):

- If the pathloss value has been specified for an earlier time, then the pathloss value specified for the most recent time is used.
- If the pathloss value has not been specified for any time instant before t_2, then N2 is assumed to be not reachable from N1 at up to and including time t_2.

(Therefore, it is only necessary to specify the pathloss for the first p channels, where p is the largest index of the channel for which the pathloss has changed from the most recent previous specification.)

2. The pathloss between two nodes can be different in each direction.

- If the pathloss from N1 to N2 on channel i at time t is defined (as specified by rule 1), then that value is used. If pathloss is not defined for time t but is defined for an earlier time instant, then the value from the most recent time is used.
- If pathloss from N1 to N2 is not defined at time t to or any previous time, but pathloss is defined from N2 to N1 at time t or an earlier time, then the pathloss defined from N2 to N1 for the most recent time (time t or earlier) is also used as the pathloss from N1 to N2.
- If pathloss is not defined from N1 to N2 or from N2 to N1 at time t or earlier, then the two nodes are unreachable from each other up to and including time t.

Example

The following lines show a segment of a pathloss matrix file.

```
Freq:2:2.4:2.6
Nodes:6

#Time    Node1    Node2    Pathloss1        Pathloss2
0        1        2        95.2400000
0        1        3        300.1510000
0        2        1        295.2400000      100.0000000

10       1        2        195.2400000      5.2400000
10       1        3        320.1510000      3.1510000
10       2        3        196.7650000      6.7650000

20       1        2        295.2400000      25.2400000
20       1        3        400.1510000      200.1510000
20       2        3        598.2400000      698.2400000
20       2        1        395.2400000      300.0000000

30       1        2        295.2400000      195.2400000
30       1        3        100.1510000      400.1510000

40       1        2        95.2400000       95.2400000
40       1        3        300.0000000      300.1510000
40       2        3        96.7650000       960.0000000


0        4        5        95.2400000
0        4        6        300.1510000
0        5        4        295.2400000      100.0000000

10       4        5        195.2400000      5.2400000
10       4        6        320.1510000      3.1510000
10       5        6        196.7650000      6.7650000

20       4        5        295.2400000      25.2400000
20       4        6        400.1510000      200.1510000
20       5        6        598.2400000      698.2400000
20       5        4        395.2400000      300.0000000

30       4        5        295.2400000      195.2400000
30       4        6        100.1510000      400.1510000

40       4        5        95.2400000       95.2400000
40       4        6        300.0000000      300.1510000
40       5        6        96.7650000       960.0000000

150      5        6        96.7650000       96.0000000
200      5        6        96.7650000       960.0000000
250      5        6        96.7650000       100.0000000
...
```

2.7.3 GUI Configuration

To configure the Pathloss Matrix Model parameters, perform the following steps:

1. Go to **Scenario Properties > Channel Properties**.
2. Set **Number of Channels** to the desired value as shown in Figure 2-14.

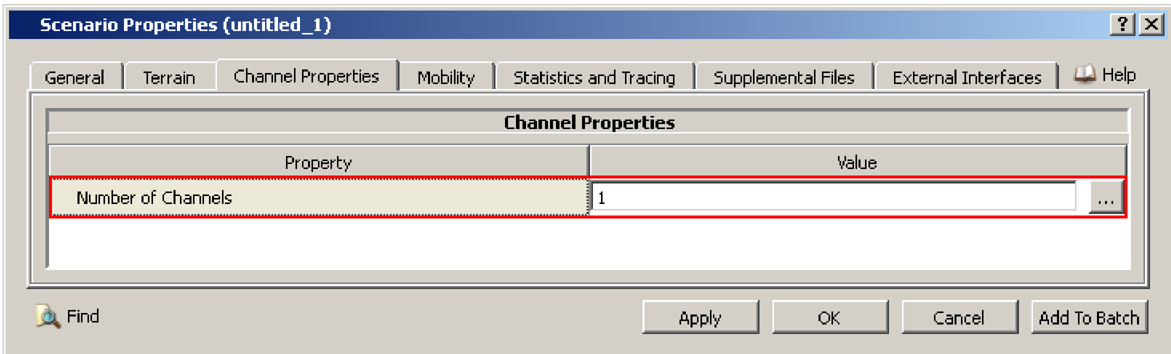

FIGURE 2-14. Setting Number of Channels

3. Click on the **Open Array Editor** ... button in the **Value** column. This opens the Array Editor.
4. In the left panel of the Array Editor, select the index of the channel to be configured. In the right panel, set **Pathloss Model** to *Pathloss Matrix*. Click **OK** to close the Array Editor.

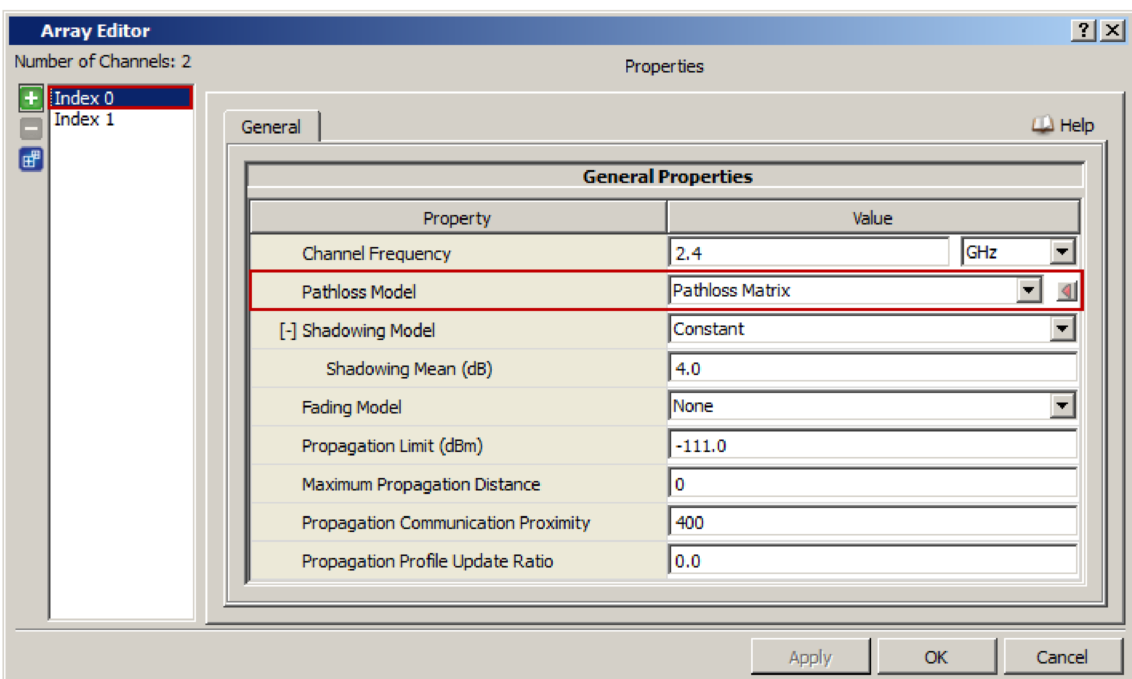

FIGURE 2-15. Setting Pathloss Model

5. In the Scenario Properties Editor, specify the name of the pathloss matrix file.

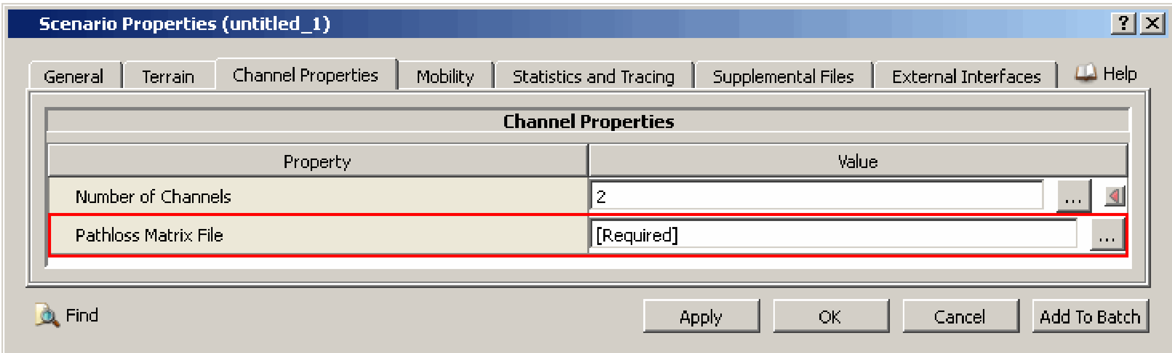

FIGURE 2-16. Setting Pathloss Matrix File

TABLE 2-12. Command Line Equivalent of Pathloss Matrix Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Pathloss Matrix File	Global	`PROPAGATION-PATHLOSS-MATRIX-FILE`

2.7.4 Statistics

There are no statistics collected by the Pathloss Matrix model.

2.8 Rayleigh Fading Model

2.8.1 Description

Rayleigh fading model is a statistical model to represent the fast variation of signal amplitude at the receiver. In wireless propagation, Rayleigh fading occurs when there is no line of sight between the transmitter and receiver. The fading speed is affected by how fast the receiver and/or transmitter, or the surrounding objects, are moving.

EXata's Rayleigh fading model uses pre-computed time series data sequence with different sample intervals to represent the different fading speeds or coherence times of the propagation channel.

2.8.2 Command Line Configuration

To select the Rayleigh fading model, include the following parameter in the scenario configuration (.config) file:

```
PROPAGATION-FADING-MODEL[<Index>]        RAYLEIGH
```

where

`<Index>` Channel index to which this parameter declaration is applicable, enclosed in square brackets. This should be in the range 0 to *n* -1, where *n* is the number of priority channels.

The index specification is optional. If an index is not included, then the parameter declaration is applicable to all channels.

Rayleigh Fading Model Parameters

Table 2-13 lists the Rayleigh fading model parameters specified in the scenario configuration (.config) file. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 2-13. Rayleigh Fading Model Parameters

Parameter Name	Value	Description
PROPAGATION-FADING-GAUSSIAN-COMPONENTS-FILE *Required* *Scope:* Global	Filename	Specifies the name of the file that stores the series of Gaussian components. The format of this file is described in Section 2.8.2.1.
PROPAGATION-FADING-MAX-VELOCITY *Required* *Scope:* Global *Instances:* channel index	Real *Range:* ≥ 0 *Unit:* meters/sec	Specifies the maximum velocity (in meters/sec) of the nodes or the surrounding objects in a scenario. In general, the fading speed increases with the motion speed.

2.8.2.1 Format of the Gaussian Components File

The first three lines of the Gaussian components file (.fading) specify the sampling rate, base Doppler frequency, and the number of Gaussian components. The first three lines have the following format:

```
SAMPLING-RATE                  <sampling rate>
BASE-DOPPLER-FREQUENCY         <base Doppler frequency>
NUMBER-OF-GAUSSIAN-COMPONENTS  <number of Gaussian components>
```

where

`<sampling rate>`	Sampling rate, in Hz.
`<base doppler frequency>`	Base Doppler frequency, in Hz.
`<number of Gaussian components>`	Number of Gaussian components in the file.

These lines are followed by `<number of Gaussian components>` lines, in the following format:

```
<Gaussian component 1>  <Gaussian component 2>
```

where

`<Gaussian component 1>:`	First Gaussian component.
`<Gaussian component 2>:`	Second Gaussian component.

A default Gaussian compounds file, default.fading, can be found in EXATA_HOME/scenarios/default. A segment of this file is shown below:

```
SAMPLING-RATE 1000
BASE-DOPPLER-FREQUENCY 30.0
NUMBER-OF-GAUSSIAN-COMPONENTS 16384

-5.6482112e-001 -1.2675110e+000
-5.7047958e-001 -1.0847877e+000
-5.6146223e-001 -8.8065119e-001
-5.4280320e-001 -6.6004259e-001
-5.1605105e-001 -4.2597880e-001
-4.7640535e-001 -1.8909923e-001
...
```

2.8.3 GUI Configuration

To configure the Rayleigh Fading Model parameters, perform the following steps:

1. Go to **Scenario Properties > Channel Properties**.
2. Set **Number of Channels** to the desired value as shown in Figure 2-17.

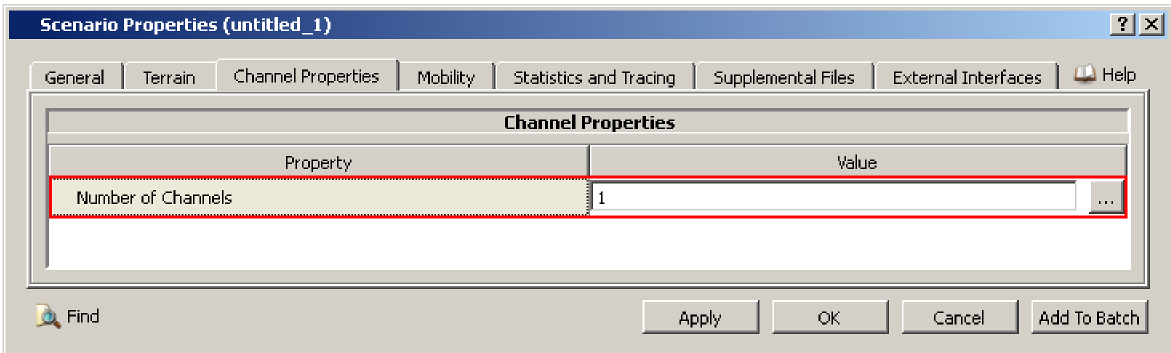

FIGURE 2-17. Setting Number of Channels

3. Click on the **Open Array Editor** ... button in the **Value** column. This opens the Array Editor.
4. In the left panel of the Array Editor, select the index of the channel to be configured. In the right panel, set **Fading Model** to *Rayleigh* and set the dependent parameters listed in Table 2-14. Click **OK** to close the Array Editor.

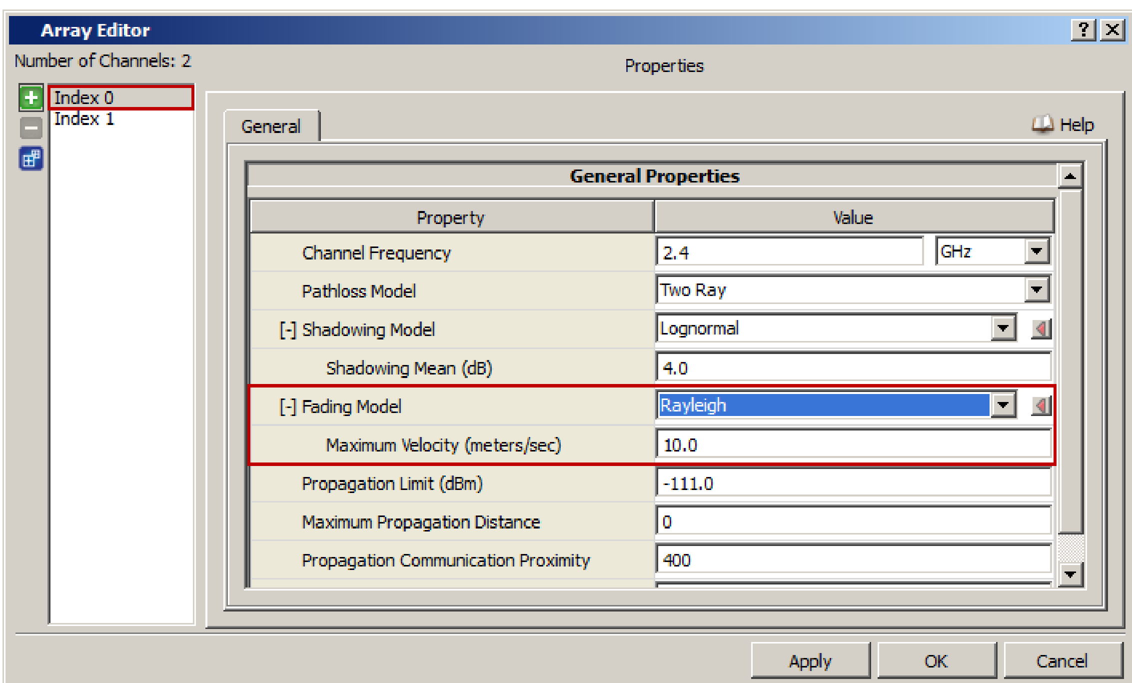

FIGURE 2-18. Setting Fading Model as Rayleigh

TABLE 2-14. Command Line Equivalent of Rayleigh Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Maximum Velocity	Global	`PROPAGATION-FADING-MAX-VELOCITY`

5. In the Scenario Properties Editor, specify the name of the Gaussian components file.

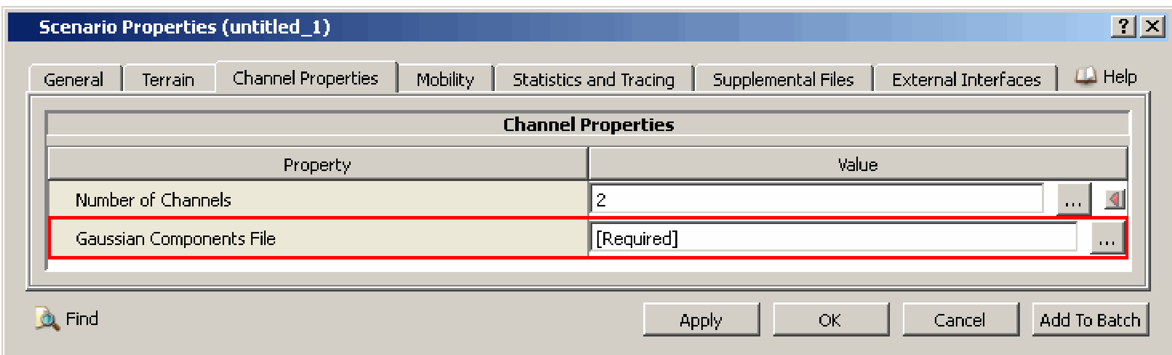

FIGURE 2-19. Setting Gaussian Components File

TABLE 2-15. Command Line Equivalent of Gaussian Components Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Gaussian Components File	Global	`PROPAGATION-FADING-GAUSSIAN-COMPONENTS-FILE`

2.8.4 Statistics

There are no statistics collected for the Rayleigh Fading model.

2.9 Ricean Fading Model

2.9.1 Description

Ricean fading model is a statistical model to represent the fast variation of signal amplitude at the receiver. In wireless propagation, Ricean fading occurs when there is line of sight between the transmitter and receiver, and the line of sight signal is the dominant signal seen at the receiver.

EXata's Ricean fading model uses pre-computed time series data sequence with different sample intervals to represent the different fading speeds or coherence times of the propagation channel.

2.9.2 Command Line Configuration

To select the Ricean fading model, include the following parameter in the scenario configuration (.config) file:

```
PROPAGATION-FADING-MODEL[<Index>]        RICEAN
```

where

`<Index>`	Channel index to which this parameter declaration is applicable, enclosed in square brackets. This should be in the range 0 to *n* -1, where *n* is the number of priority channels. The index specification is optional. If an index is not included, then the parameter declaration is applicable to all channels.

Ricean Fading Model Parameters

Table 2-16 describes the Ricean fading model parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 2-16. Ricean Fading Model Parameters

Parameter Name	Value	Description
`PROPAGATION-FADING-GAUSSIAN-COMPONENTS-FILE` *Required* *Scope:* Global	Filename	Specifies the name of the file that stores the series of Gaussian components. The format of this file is described in Section 2.9.2.1.
`PROPAGATION-FADING-MAX-VELOCITY` *Required* *Scope:* Global *Instances:* channel index	Real *Range:* ≥ 0 *Unit:* meters/sec	Specifies the maximum velocity of the nodes or the surrounding objects in the scenario. **Note:** In general, the fading speed increases with the motion speed.
`PROPAGATION-RICEAN-K-FACTOR` *Required* *Scope:* Global *Instances:* channel index	Real *Range:* ≥ 0	Specifies the Ricean K factor (linear value). The K factor specifies the ratio of the signal power of the dominant component to the scattered power.

2.9.2.1 Format of the Gaussian Components File

The first three lines of the Gaussian components file (.fading) specify the sampling rate, base doppler frequency, and the number of Gaussian components. The first three lines have the following format:

```
SAMPLING-RATE                  <sampling rate>
BASE-DOPPLER-FREQUENCY         <base Doppler frequency>
NUMBER-OF-GAUSSIAN-COMPONENTS  <num Gaussian components>
```

where

`<sampling rate>` : Sampling rate, in Hz.

`<base Doppler frequency>` : Base Doppler frequency, in Hz.

`<num Gaussian components>` : Number of Gaussian components in the file.

These lines are followed by `<num Gaussian components>` lines, each in the following format:

```
<Gaussian component 1>  <Gaussian component 2>
```

where

`<Gaussian component 1>` : First Gaussian component.

`<Gaussian component 2>` : Second Gaussian component.

A default Gaussian components file, default.fading, can be found in EXATA_HOME/scenarios/default. A segment of this file is shown below:

```
SAMPLING-RATE 1000
BASE-DOPPLER-FREQUENCY 30.0
NUMBER-OF-GAUSSIAN-COMPONENTS 16384

-5.6482112e-001 -1.2675110e+000
-5.7047958e-001 -1.0847877e+000
-5.6146223e-001 -8.8065119e-001
-5.4280320e-001 -6.6004259e-001
-5.1605105e-001 -4.2597880e-001
-4.7640535e-001 -1.8909923e-001
...
```

2.9.3 GUI Configuration

To configure the Ricean model parameters, perform the following steps:

1. Go to **Scenario Properties > Channel Properties**.
2. Set **Number of Channels** to the desired value as shown in Figure 2-20.

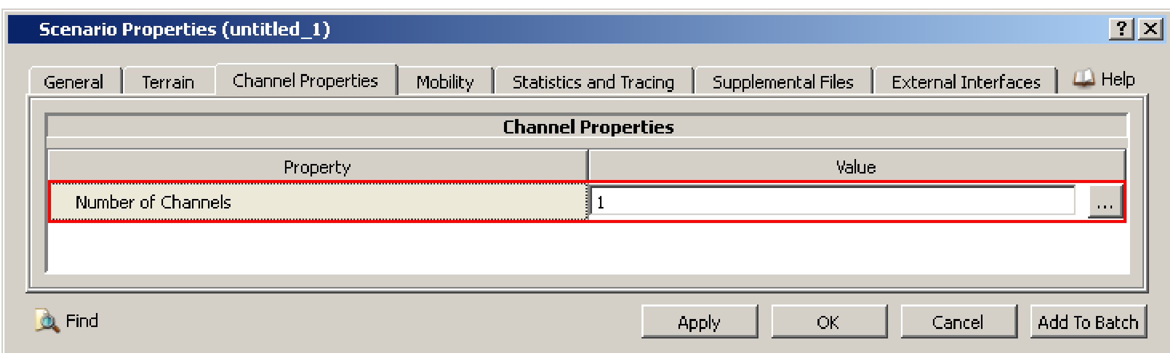

FIGURE 2-20. Setting Number of Channels

3. Click on the **Open Array Editor** ... button in the **Value** column. This opens the Array Editor.

4. In the left panel of the Array Editor, select the index of the channel to be configured. In the right panel, set **Fading Model** to *Ricean* and set the dependent parameters listed in Table 2-17. Click **OK** to close the Array Editor.

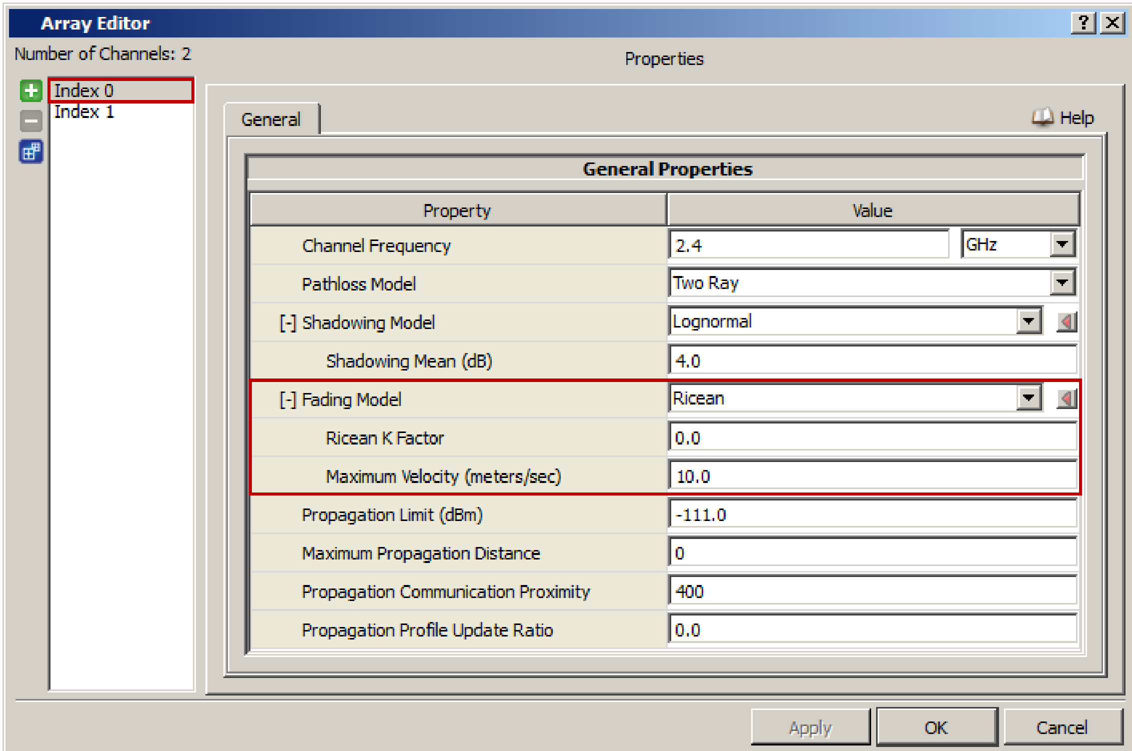

FIGURE 2-21. Setting Ricean Model Parameters

TABLE 2-17. Command Line Equivalent of Ricean Model Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Ricean K Factor	Global	PROPAGATION-RICEAN-K-FACTOR
Maximum Velocity	Global	PROPAGATION-FADING-MAX-VELOCITY

5. In the Scenario Properties Editor, specify the name of the Gaussian components file.

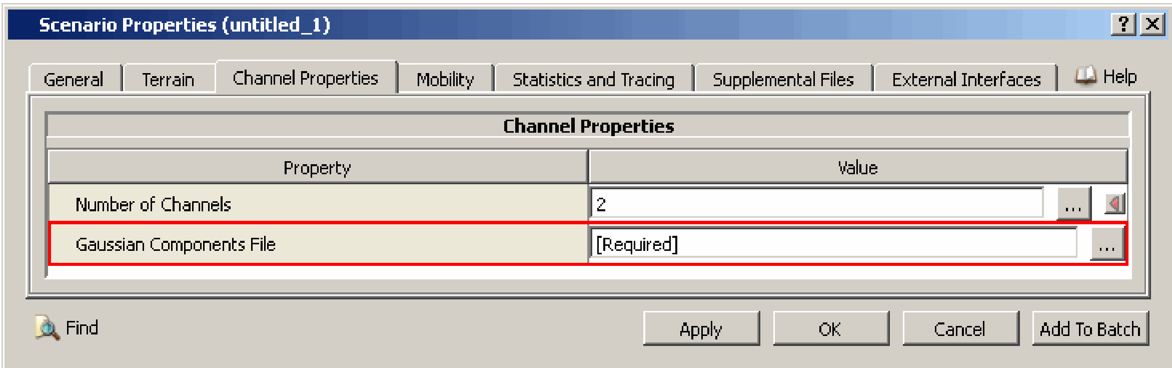

FIGURE 2-22. Setting Gaussian Components File

TABLE 2-18. Command Line Equivalent of Gaussian Components File

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Gaussian Components File	Global	`PROPAGATION-FADING-GAUSSIAN-COMPONENTS-FILE`

2.9.4 Statistics

There are no statistics collected for the Ricean Fading model.

2.10 Two-ray Pathloss Model

2.10.1 Description

The Two-ray pathloss model uses free space pathloss for the direct line-of-sight propagation path and the reflection from flat earth. For the reflected signal, the signal strength decays as the fourth power of the distance between the transmitter and receiver assuming that the distance is much larger than the product of antenna heights.

2.10.2 Command Line Configuration

To select the Two-ray pathloss model, include the following parameter in the scenario configuration (.config) file:

```
PROPAGATION-PATHLOSS-MODEL[<Index>]     TWO-RAY
```

where

`<Index>`	Channel index to which this parameter declaration is applicable, enclosed in square brackets. This should be in the range 0 to *n* -1, where *n* is the number of priority channels. The index specification is optional. If an index is not included, then the parameter declaration is applicable to all channels.

Two-ray Pathloss Model Parameters

There are no additional configuration parameters for the Two-ray pathloss model.

2.10.3 GUI Configuration

To configure the Two Ray Pathloss Model parameters, perform the following steps:

1. Go to **Scenario Properties > Channel Properties**.
2. Set **Number of Channels** to the desired value as shown in Figure 2-23.

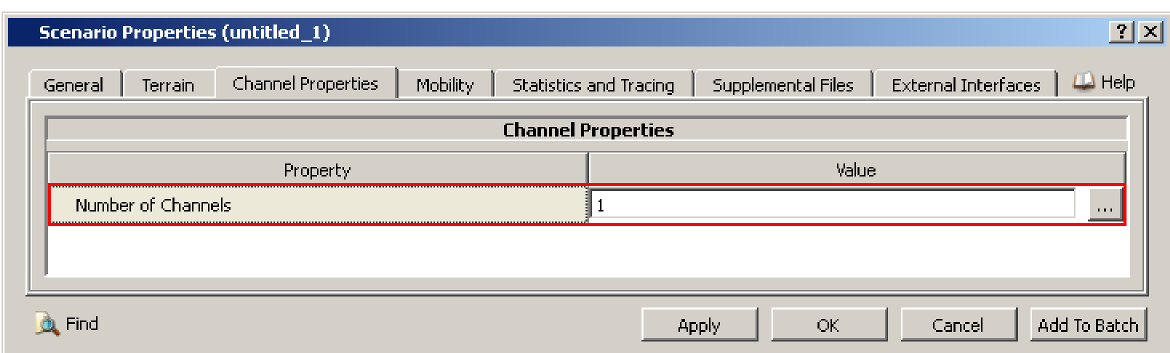

FIGURE 2-23. Setting Number of Channels

3. Click on the **Open Array Editor** [...] button in the **Value** column. This opens the Array Editor.
4. In the left panel of the Array Editor, select the index of the channel to be configured. In the right panel, set **Pathloss Model** to *Two Ray*. There are no dependent parameters for this model.

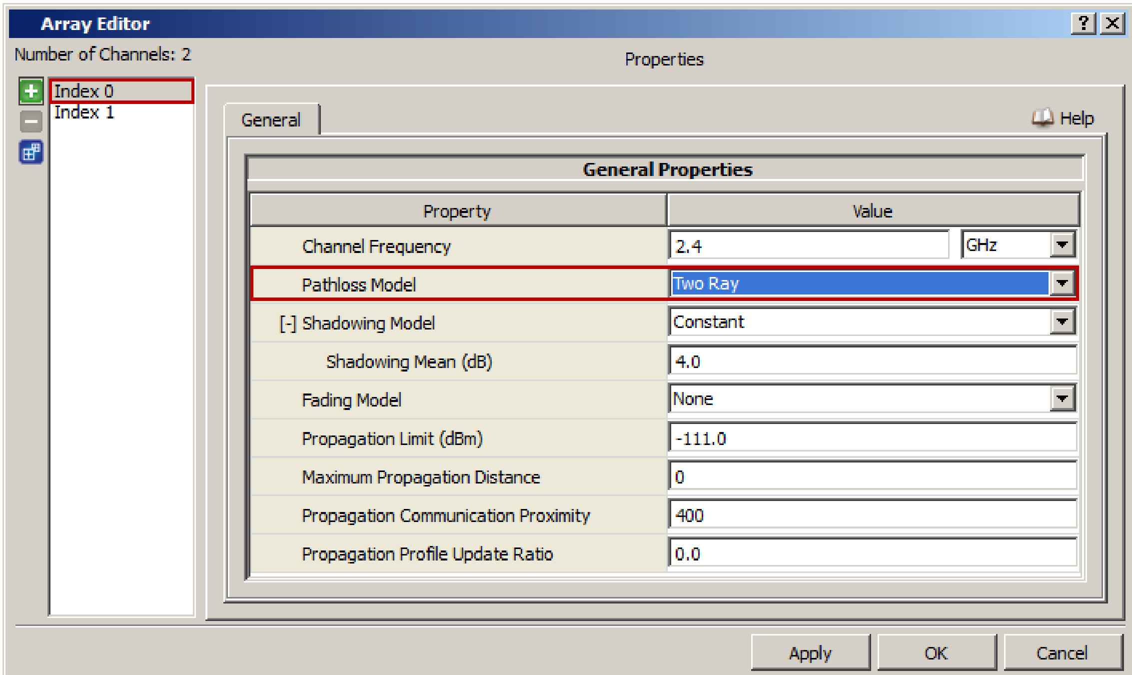

FIGURE 2-24. Setting Pathloss Model as Two Ray

2.10.4 Statistics

There are no statistics collected for the Two-ray pathloss model.

3 Physical Layer Models

This chapter describes features, configuration requirements and parameters, statistics, and scenarios for Physical Layer Models, and consists of the following sections:

- 802.11a/g PHY Model
- 802.11b PHY Model
- 802.11n PHY Model
- Abstract PHY Model
- Antenna Models
- Bit Error Rate-based (BER) Reception Model
- Radio Energy Models
- SNR-based Reception Model

3.1 802.11a/g PHY Model

The EXata 802.11a/g PHY model is based on the following documents:

- IEEE Std 802.11a–1999.
- IEEE Std 802.11–1999.
- The IEEE 802.11 Handbook: A Designers Companion.

3.1.1 Description

802.11a PHY is an extension to IEEE 802.11 PHY that applies to wireless LANs and provides up to 54 Mbps in the 5-GHz band. 802.11a PHY uses an orthogonal frequency division multiplexing encoding scheme rather than FHSS or DSSS.

3.1.2 Command Line Configuration

To select 802.11a PHY as the PHY model, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>] PHY-MODEL          PHY802.11a
```

The scope of this parameter declaration can be Global, Node, Subnet or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

802.11a/g PHY Parameters

Table 3-1 lists the 802.11a/g PHY parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 3-1. 802.11a/g PHY Parameters

Parameter	Value	Description
`PHY802.11-AUTO-RATE-FALLBACK` *Optional* *Scope:* All	List: • `YES` • `NO` *Default:* `NO`	Specifies whether dynamic switching of data-rate based on distance between nodes is enabled.
`PHY802.11a-TX-POWER-6MBPS` *Optional* *Scope:* All	Real *Range:* `> 0` *Default:* `20` *Unit:* dBm	Sets the transmission power in dBm for the nodes using 802.11a PHY at 6-Mbps data rate.
`PHY802.11a-TX-POWER-9MBPS` *Optional* *Scope:* All	Real *Range:* `> 0` *Default:* `20` *Unit:* dBm	Sets the transmission power in dBm for the nodes using 802.11a PHY at 9Mbps data rate.

TABLE 3-1. 802.11a/g PHY Parameters (Continued)

Parameter	Value	Description
PHY802.11a-TX-POWER-12MBPS *Optional* *Scope:* All	Real *Range:* > 0 *Default:* 19 *Unit:* dBm	Sets the transmission power in dBm for the nodes using 802.11a PHY at 12Mbps data rate.
PHY802.11a-TX-POWER-18MBPS *Optional* *Scope:* All	Real *Range:* > 0 *Default:* 19 *Unit:* dBm	Sets the transmission power in dBm for the nodes using 802.11a PHY at 18Mbps data rate.
PHY802.11a-TX-POWER-24MBPS *Optional* *Scope:* All	Real *Range:* > 0 *Default:* 18 *Unit:* dBm	Sets the transmission power in dBm for the nodes using 802.11a PHY at 24Mbps data rate.
PHY802.11a-TX-POWER-36MBPS *Optional* *Scope:* All	Real *Range:* > 0 *Default:* 18 *Unit:* dBm	Sets the transmission power in dBm for the nodes using 802.11a PHY at 36Mbps data rate.
PHY802.11a-TX-POWER-48MBPS *Optional* *Scope:* All	Real *Range:* > 0 *Default:* 16 *Unit:* dBm	Sets the transmission power in dBm for the nodes using 802.11a PHY at 48Mbps data rate.
PHY802.11a-TX-POWER-54MBPS *Optional* *Scope:* All	Real *Range:* > 0 *Default:* 16 *Unit:* dBm	Sets the transmission power in dBm for the nodes using 802.11a PHY at 54Mbps data rate.
PHY802.11a-RX-SENSITIVITY-6MBPS *Optional* *Scope:* All	Real *Default:* -85 *Unit:* dBm	Sets the receiver sensitivity in dBm for the nodes using 802.11a PHY at 6Mbps data rate.
PHY802.11a-RX-SENSITIVITY-9MBPS *Optional* *Scope:* All	Real *Default:* -85 *Unit:* dBm	Sets the receiver sensitivity in dBm for the nodes using 802.11a PHY at 9Mbps data rate.

TABLE 3-1. 802.11a/g PHY Parameters (Continued)

Parameter	Value	Description
PHY802.11a-RX-SENSITIVITY-12MBPS *Optional* *Scope:* All	Real *Default:* -83 *Unit:* dBm	Sets the receiver sensitivity in dBm for the nodes using 802.11a PHY at 12Mbps data rate.
PHY802.11a-RX-SENSITIVITY-18MBPS *Optional* *Scope:* All	Real *Default:* -83 *Unit:* dBm	Sets the receiver sensitivity in dBm for the nodes using 802.11a PHY at 18Mbps data rate.
PHY802.11a-RX-SENSITIVITY-24MBPS *Optional* *Scope:* All	Real *Default:* -78 *Unit:* dBm	Sets the receiver sensitivity in dBm for the nodes using 802.11a PHY at 24Mbps data rate.
PHY802.11a-RX-SENSITIVITY-36MBPS *Optional* *Scope:* All	Real *Default:* -78 *Unit:* dBm	Sets the receiver sensitivity in dBm for the nodes using 802.11a PHY at 36Mbps data rate.
PHY802.11a-RX-SENSITIVITY-48MBPS *Optional* *Scope:* All	Real *Default:* -69 *Unit:* dBm	Sets the receiver sensitivity in dBm for the nodes using 802.11a PHY at 48Mbps data rate.
PHY802.11a-RX-SENSITIVITY-54MBPS *Optional* *Scope:* All	Real *Default:* -69 *Unit:* dBm	Sets the receiver sensitivity in dBm for the nodes using 802.11a PHY at 54Mbps data rate.
PHY802.11-DATA-RATE *Optional* *Scope:* All	List: • *6000000* • 9000000 • 12000000 • 18000000 • 24000000 • 36000000 • 48000000 • 54000000 *Default:* *6000000*	Specifies the fixed data rate (in bits/sec) to use if auto rate fallback is disabled. **Note:** This parameter is applicable only if PHY802.11-AUTO-RATE-FALLBACK is set to NO.

TABLE 3-1. 802.11a/g PHY Parameters (Continued)

Parameter	Value	Description
PHY802.11-DATA-RATE-FOR-BROADCAST *Optional* *Scope:* All	List: • 6000000 • 9000000 • 12000000 • 18000000 • 24000000 • 36000000 • 48000000 • 54000000 *Default:* 54000000	Specifies the data rate (in bits/sec) for broadcast. It must be either one of the multirate or same as the data rate in single rate service.
PHY802.11-ESTIMATED-DIRECTIONAL-ANTENNA-GAIN *Optional* *Scope:* All	Real *Default:* 15.0 *Unit:* dBm	Specifies the estimated directional antenna gain. **Note:** This parameter is applicable only if the antenna model is Switched Beam or Steerable.
PHY-RX-MODEL *Required* *Scope:* All	List: • BER-BASED • PHY802.11a	Specifies the packet reception model. See Section 3.6 for details of the BER-based reception model.
PHY-LAYER-STATISTICS *Optional* *Scope:* All	List: • YES • NO *Default:* NO	Indicates whether statistics are collected for the physical layer protocols, including 802.11a/g.

3.1.3 GUI Configuration

This section describes how to configure 802.11a/g PHY model in the GUI.

Configuring 802.11a/g PHY Model Parameters

To configure the 802.11a/g PHY parameters, perform the following steps:

1. Go to one of the following locations:
   - To set properties for a specific subnet, go to **Wireless Subnet Properties Editor > Physical Layer**.
   - To set properties a specific interface of a node, go to one of the following locations:
     - **Interface Properties Editor > Interfaces > Interface # > Physical Layer**.
     - **Default Device Properties Editor > Interfaces > Interface # > Physical Layer**.

   In this section, we show how to configure 802.11a/g PHY parameters for a specific interface using the Default Device Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **Radio Type** to *802.11a/g Radio* and set dependent parameters of the model, as listed in Table 3-2.

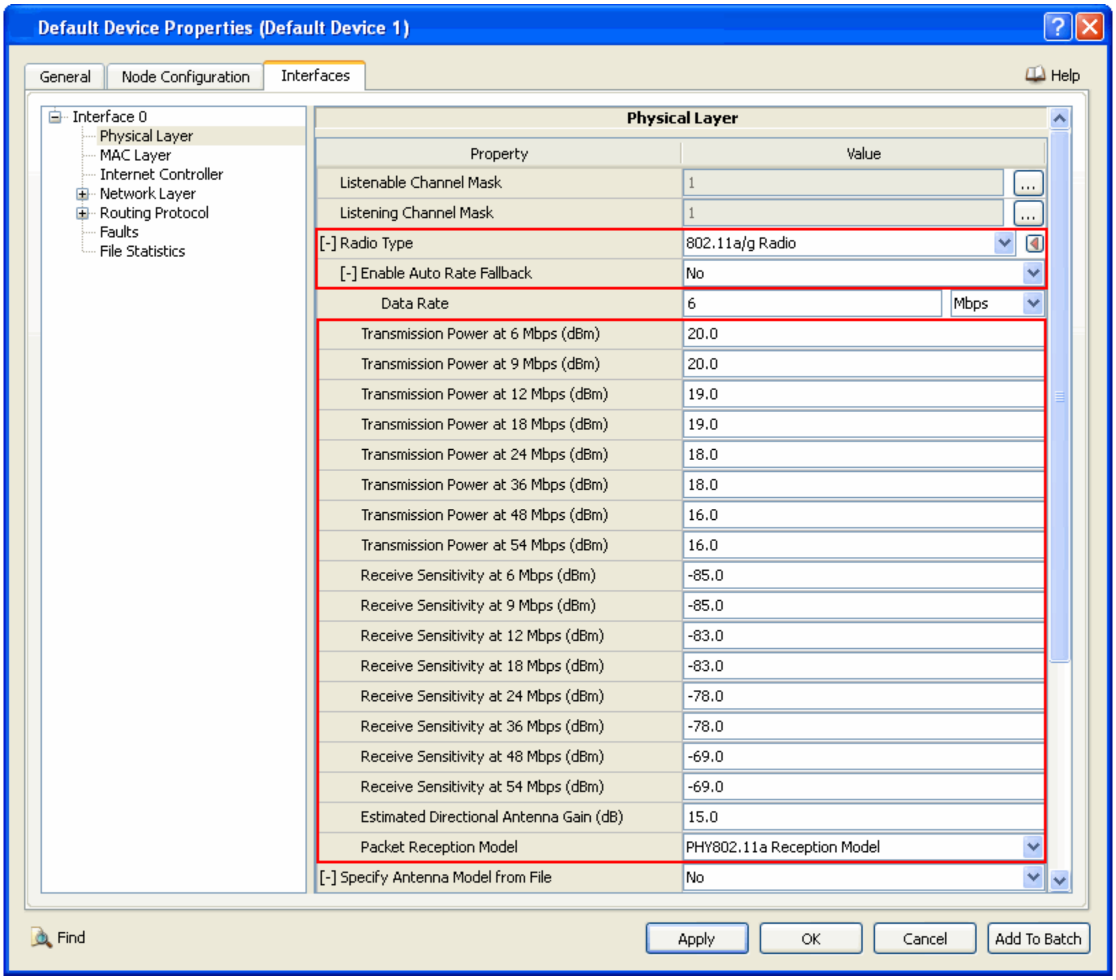

FIGURE 3-1. Setting 802.11a/g PHY Parameters

TABLE 3-2. Command Line Equivalent of 802.11b PHY Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Enable Auto Rate Fallback	Subnet, Interface	`PHY802.11-AUTO-RATE-FALLBACK`
Transmission Power at 6 Mbps	Subnet, Interface	`PHY802.11a-TX-POWER-6MBPS`
Transmission Power at 9 Mbps	Subnet, Interface	`PHY802.11a-TX-POWER-9MBPS`
Transmission Power at 12 Mbps	Subnet, Interface	`PHY802.11a-TX-POWER-12MBPS`
Transmission Power at 18 Mbps	Subnet, Interface	`PHY802.11a-TX-POWER-18MBPS`
Transmission Power at 24 Mbps	Subnet, Interface	`PHY802.11a-TX-POWER-24MBPS`
Transmission Power at 36 Mbps	Subnet, Interface	`PHY802.11a-TX-POWER-36MBPS`
Transmission Power at 48 Mbps	Subnet, Interface	`PHY802.11a-TX-POWER-48MBPS`
Transmission Power at 54 Mbps	Subnet, Interface	`PHY802.11a-TX-POWER-54MBPS`
Receive Sensitivity at 6 Mbps	Subnet, Interface	`PHY802.11a-RX-SENSITIVITY-6MBPS`
Receive Sensitivity at 9 Mbps	Subnet, Interface	`PHY802.11a-RX-SENSITIVITY-9MBPS`
Receive Sensitivity at 12 Mbps	Subnet, Interface	`PHY802.11a-RX-SENSITIVITY-12MBPS`
Receive Sensitivity at 18 Mbps	Subnet, Interface	`PHY802.11a-RX-SENSITIVITY-18MBPS`
Receive Sensitivity at 24 Mbps	Subnet, Interface	`PHY802.11a-RX-SENSITIVITY-24MBPS`
Receive Sensitivity at 36 Mbps	Subnet, Interface	`PHY802.11a-RX-SENSITIVITY-36MBPS`
Receive Sensitivity at 48 Mbps	Subnet, Interface	`PHY802.11a-RX-SENSITIVITY-48MBPS`
Receive Sensitivity at 54 Mbps	Subnet, Interface	`PHY802.11a-RX-SENSITIVITY-54MBPS`
Estimated Directional Antenna Gain	Subnet, Interface	`PHY802.11-ESTIMATED-DIRECTIONAL-ANTENNA-GAIN`
Packet Reception Model	Subnet, Interface	`PHY-RX-MODEL`

Setting Parameters

- To enable Auto Rate Fallback, set **Enable Auto Rate Fallback** to *Yes*; otherwise set **Enable Auto Rate Fallback** to *No*.
- To use default BER tables, set **Packet Reception Model** to *PHY802.11a Reception Model*. To specify BER tables, set **Packet Reception Model** to *BER-based Reception Model* and configure the BER tables as described in Section 3.6.

3. If **Enable Auto Rate Fallback** is set to *Yes*, then set the dependent parameters listed in Table 3-3.

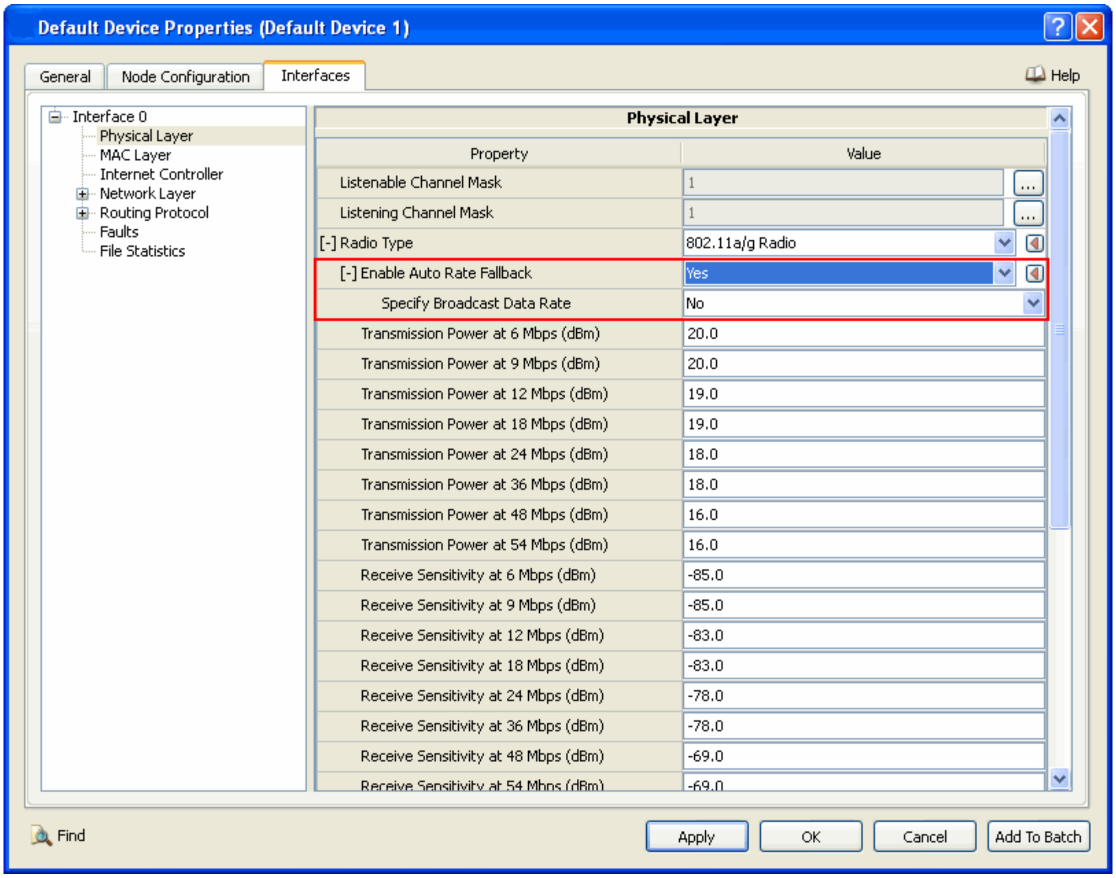

FIGURE 3-2. Setting Auto Rate Fallback Parameters

TABLE 3-3. Command Line Equivalent of Auto Rate Fallback Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Specify Broadcast Data Rate	Subnet, Interface	N/A

Setting Parameters

- To specify Broadcast data rate, set **Specify Broadcast Data Rate** to *Yes*, otherwise set **Specify Broadcast Data Rate** to *No*. Specify Broadcast Data Rate is a GUI-only parameter and does not have command line equivalent.

4. If **Specify Broadcast Data Rate** is set to *Yes*, then set the dependent parameters listed in Table 3-4.

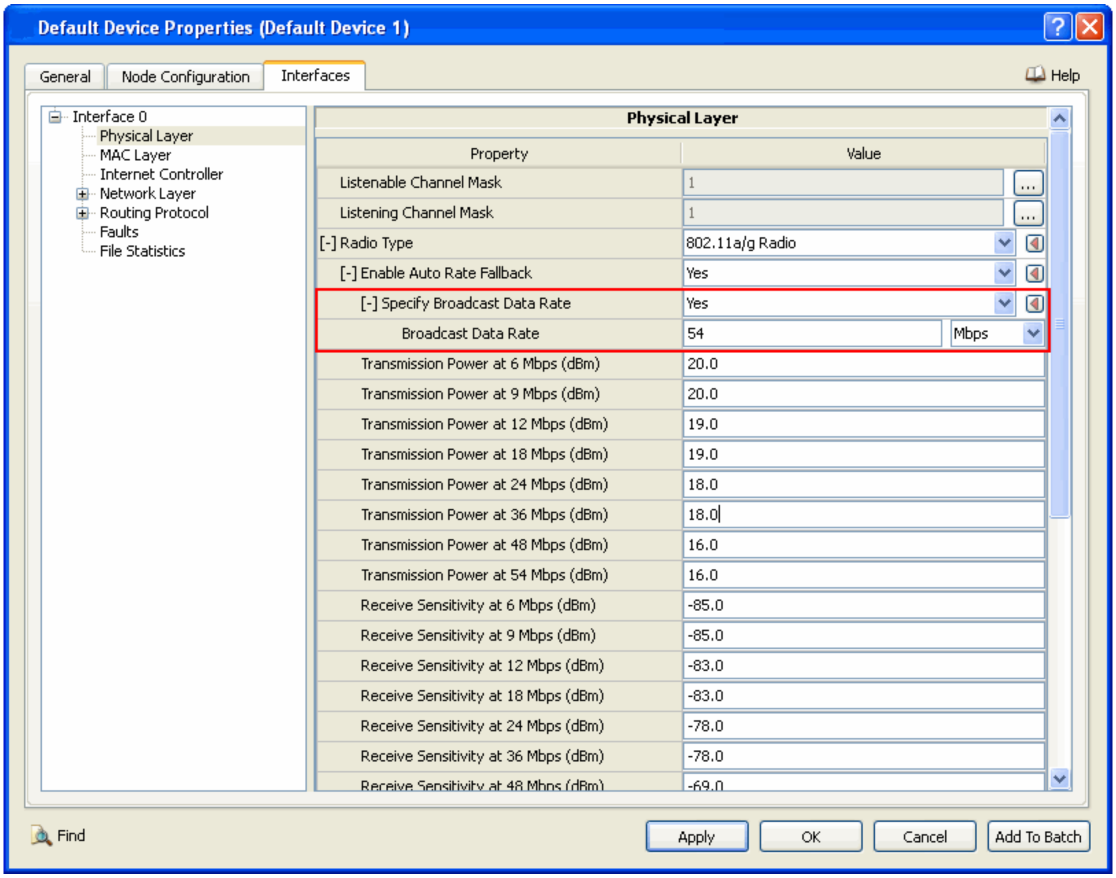

FIGURE 3-3. Setting Broadcast Data Rate Parameters

TABLE 3-4. Command Line Equivalent of Broadcast Data Rate Parameter

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Broadcast Data Rate	Subnet, Interface	`PHY802.11-DATA-RATE-FOR-BROADCAST`

5. If **Enable Auto Rate Fallback** is set to *No*, then set the dependent parameters listed in Table 3-5.

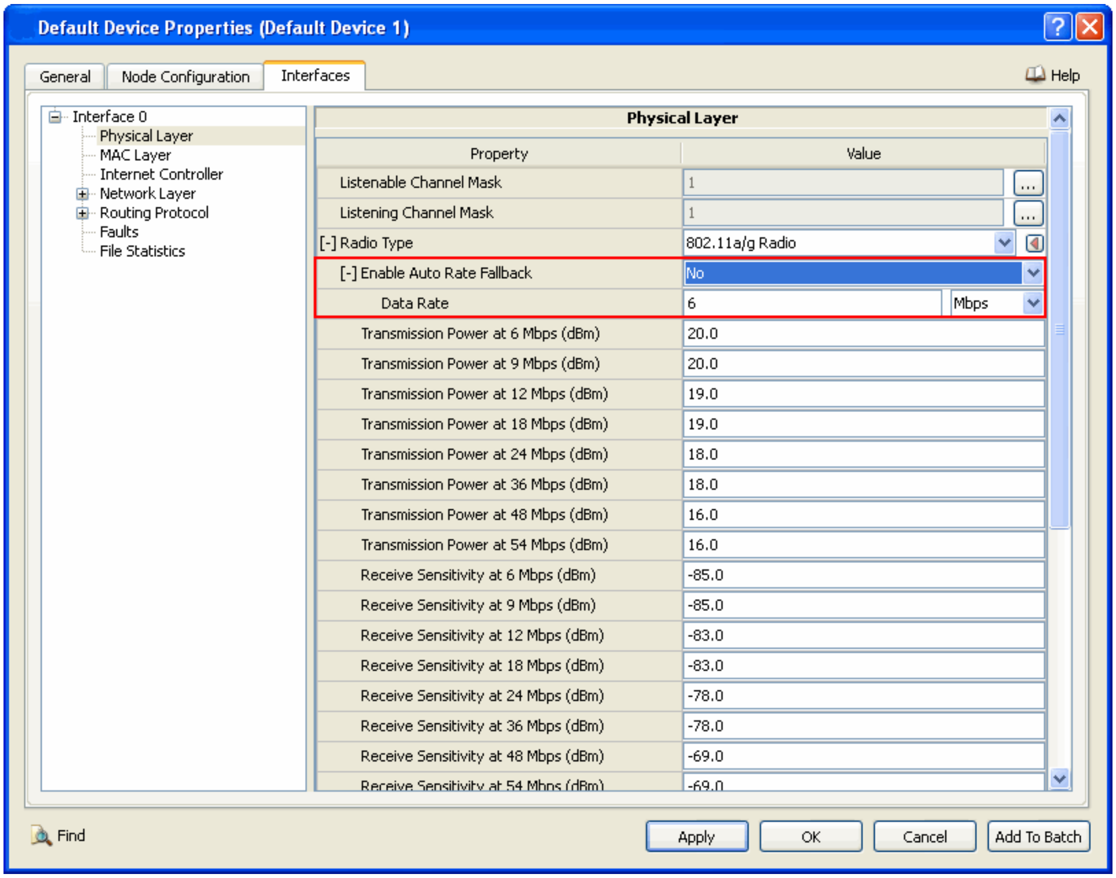

FIGURE 3-4. Setting Data Rate

TABLE 3-5. Command Line Equivalent of Enable Auto Rate Fallback Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Data Rate	Subnet, Interface	`PHY802.11-DATA-RATE`

Configuring Statistics Parameters

Statistics for the 802.11a/g PHY model can be collected at the global, node, subnet, and interface levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for 802.11a/g PHY, check the box labeled **PHY/Radio** in the appropriate properties editor.

TABLE 3-6. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
PHY/Radio	Global, Node, Subnet, Interface	`PHY-LAYER-STATISTICS`

3.1.4 Statistics

This section describes the file, database and dynamic statistics of the 802.11a/g PHY model.

3.1.4.1 File Statistics

Table 3-7 shows the 802.11a/g PHY model statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 3-7. 802.11a/g PHY Statistics

Statistic	Description
Signals transmitted (signals)	Number of signals transmitted
Signals detected (signals)	Number of signals detected by PHY
Signals locked (signals)	Number of signals locked on by PHY
Signals received with errors (signals)	Number of signals received with errors
Signals received with interference (signals)	Number of signals received with interference
Signals sent to mac (signals)	Number of signals sent to MAC
Time spent transmitting (seconds)	Time spent in transmitting signal
Time spent receiving (seconds)	Time spent in receiving signal
Average transmission delay (seconds)	Average transmission delay
Utilization (percent/100)	Total utilization
Average signal power (dBm)	Average signal power
Average interference (dBm)	Average interference
Average pathloss (dB)	Average pathloss

3.1.4.2 Database Statistics

In addition to the file statistics, the 802.11a/g PHY model also enters statistics in various scenario statistics database tables. Refer to *EXata Statistics Database User's Guide* for details.

3.1.4.3 Dynamic Statistics

No dynamic statistics are supported for the 802.11a/g PHY model.

3.1.5 References

1. IEEE Std 802.11a–1999, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band." September 16, 1999.
2. IEEE Std 802.11–1999, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications." March 18, 1999.

3. Bob O'Hara, Al Petrick.*The IEEE 802.11 Handbook: A Designers Companion. United States Of America:Standards Information Network* IEEE Press.

3.2 802.11b PHY Model

The EXata 802.11b PHY model is based on the following documents:

- IEEE Std 802.11b–1999.
- IEEE Std 802.11–1999.
- The IEEE 802.11 Handbook A Designer's Companion:A Designers Companion.

3.2.1 Description

802.11b PHY is an extension to IEEE 802.11 PHY that applies to wireless LANS and provides 11 Mbps transmission (with a fallback to 5.5, 2 and 1 Mbps) in the 2.4 GHz band. 802.11b PHY uses only Direct-Sequence Spread-Spectrum (DSSS) modulation. 802.11b PHY was a 1999 ratification to the original 802.11 PHY standard, allowing wireless functionality comparable to Ethernet.

802.11b is a direct extension of the DSSS modulation technique. As with other spread-spectrum technologies, the signal transmitted using DSSS takes up more bandwidth than the information signal that is being modulated. The carrier signals occur over the full bandwidth (spectrum) of a device transmitting frequency. DSSS modulates the signal by multiplying the data being transmitted by a "noise" signal. This noise signal is a pseudorandom sequence of 1 and -1 values, at a frequency much higher than that of the original signal, thereby spreading the energy of the original signal into a much wider band.

The 802.11b standard uses Complementary code keying (CCK) as its modulation technique, which is a variation on CDMA. Complementary codes are sets of finite sequences of equal length, such that the number of pairs of identical elements with any given separation in one sequence is equal to the number of pairs of unlike elements having the same separation in the other sequences. CCK is a variation and improvement on, M-ary Orthogonal Keying and uses "polyphase complementary codes".

3.2.2 Command Line Configuration

To select 802.11b PHY as the PHY model, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>] PHY-MODEL          PHY802.11b
```

The scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

802.11b PHY Parameters

Table 3-8 lists the 802.11b PHY parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 3-8. 802.11b PHY Parameters

Parameter	Value	Description
`PHY802.11-AUTO-RATE-FALLBACK` *Optional* *Scope:* All	List: • `YES` • `NO` *Default:* `NO`	Specifies whether dynamic switching of data-rate based on distance between nodes is enabled.
`PHY802.11b-TX-POWER-1MBPS` *Optional* *Scope:* All	Real *Default:* `15` *Unit:* dBm	Sets the transmission power in dBm for the nodes using 802.11b PHY at the 1Mbps data rate.
`PHY802.11b-TX-POWER-2MBPS` *Optional* *Scope:* All	Real *Default:* `15` *Unit:* dBm	Sets the transmission power in dBm for the nodes using 802.11b PHY at the 2Mbps data rate.
`PHY802.11b-TX-POWER-6MBPS` *Optional* *Scope:* All	Real *Default:* `15` *Unit:* dBm	Sets the transmission power in dBm for the nodes using 802.11b PHY at the 5.5Mbps data rate.
`PHY802.11b-TX-POWER-11MBPS` *Optional* *Scope:* All	Real *Default:* `15` *Unit:* dBm	Sets the transmission power in dBm for the nodes using 802.11b PHY at the 11Mbps data rate.
`PHY802.11b-RX-SENSITIVITY-1MBPS` *Optional* *Scope:* All	Real *Default:* `-94` *Unit:* dBm	Sets the receiver sensitivity in dBm for the nodes using 802.11b PHY at the 1Mbps data rate.
`PHY802.11b-RX-SENSITIVITY-2MBPS` *Optional* *Scope:* All	Real *Default:* `-91` *Unit:* dBm	Sets the receiver sensitivity in dBm for the nodes using 802.11b PHY at the 2Mbps data rate.
`PHY802.11b-RX-SENSITIVITY-6MBPS` *Optional* *Scope:* All	Real *Default:* `-87` *Unit:* dBm	Sets the receiver sensitivity in dBm for the nodes using 802.11b PHY at the 5.5Mbps data rate.

TABLE 3-8. 802.11b PHY Parameters (Continued)

Parameter	Value	Description
PHY802.11b-RX-SENSITIVITY-11MBPS *Optional* *Scope:* All	Real *Default:* -83 *Unit:* dBm	Sets the receiver sensitivity in dBm for the nodes using 802.11b PHY at the 11Mbps data rate.
PHY802.11-DATA-RATE *Optional* *Scope:* All	List: • 6000000 • 9000000 • 12000000 • 18000000 • 24000000 • 36000000 • 48000000 • 54000000 *Default:* 6000000	Specifies the fixed data rate (in bits/sec) to use if auto rate fallback is disabled. **Note:** This parameter is applicable only if PHY802.11-AUTO-RATE-FALLBACK is set to NO.
PHY802.11-DATA-RATE-FOR-BROADCAST *Optional* *Scope:* All	List: • 6000000 • 9000000 • 12000000 • 18000000 • 24000000 • 36000000 • 48000000 • 54000000 *Default:* 54000000	Specifies the data rate (in bits/sec) for broadcast. It must be either one of the multirate or same as the data rate in single rate service.
PHY802.11-ESTIMATED-DIRECTIONAL-ANTENNA-GAIN *Optional* *Scope:* All	Real *Default:* 15.0 *Unit:* dBm	Estimated antenna gain (in dBm) for directional communication. **Note:** This parameter is applicable only if the antenna model is Switched Beam or Steerable.
PHY-RX-MODEL *Required* *Scope:* All	List: • BER-BASED • PHY802.11b	Specifies the packet reception model. See Section 3.6 for details of the BER-based reception model.
PHY-LAYER-STATISTICS *Optional* *Scope:* All	List: • YES • NO *Default:* NO	Indicates whether statistics are collected for the physical layer protocols, including 802.11b PHY.

3.2.3 GUI Configuration

This section describes how to configure 802.11b PHY model in the GUI.

Configuring 802.11b PHY Model Parameters

To configure the 802.11b PHY parameters, perform the following steps:

1. Go to one of the following locations:
   - To set properties for a specific subnet, go to **Wireless Subnet Properties Editor > Physical Layer**.
   - To set properties a specific interface of a node, go to one of the following locations:
     - **Interface Properties Editor > Interfaces > Interface # > Physical Layer**.
     - **Default Device Properties Editor > Interfaces > Interface # > Physical Layer**.

   In this section, we show how to configure 802.11b PHY parameters for a specific interface using the Default Device Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **Radio Type** to *802.11b Radio* and set dependent parameters of the model, as listed in Table 3-9.

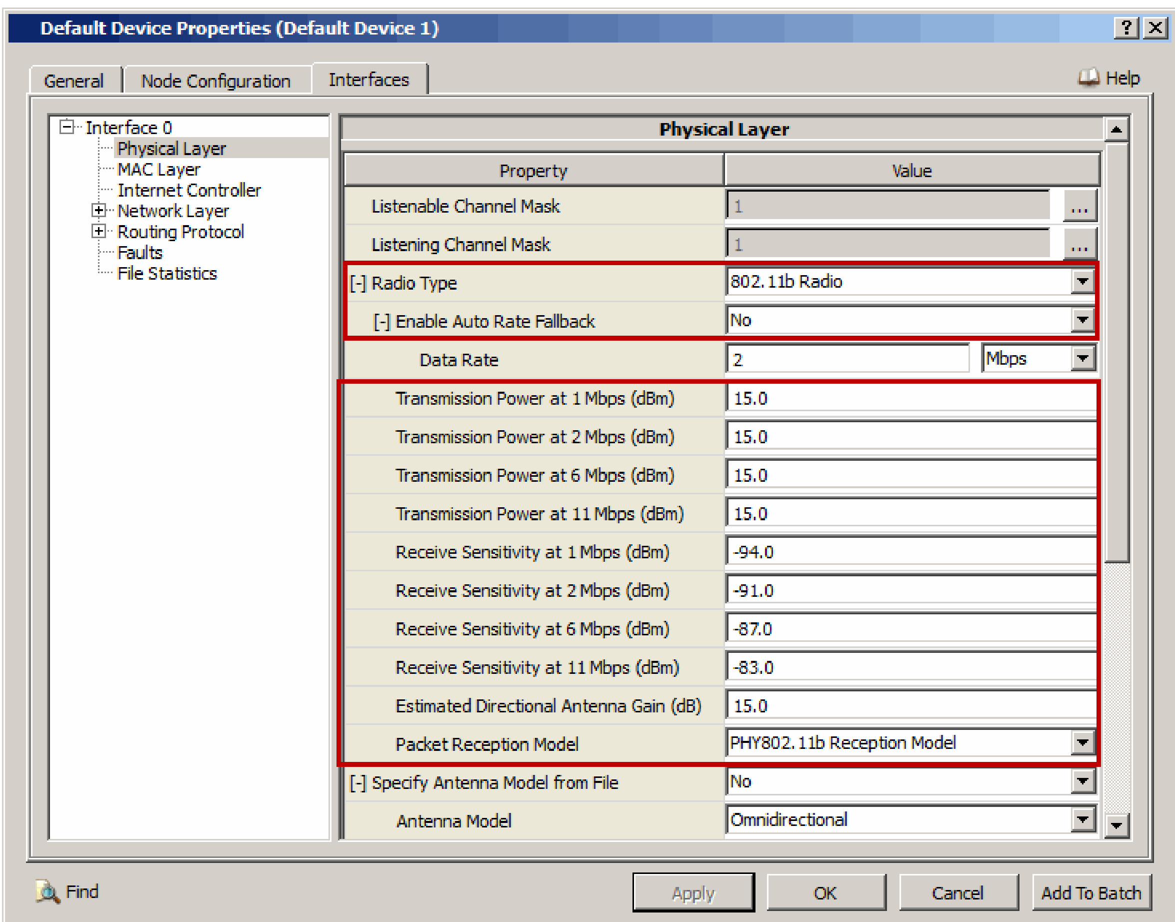

FIGURE 3-5. Setting 802.11b PHY Parameters

TABLE 3-9. Command Line Equivalent of 802.11b PHY Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Enable Auto Rate Fallback	Subnet, Interface	PHY802.11-AUTO-RATE-FALLBACK
Transmission Power at 1 Mbps	Subnet, Interface	PHY802.11b-TX-POWER-1MBPS
Transmission Power at 2 Mbps	Subnet, Interface	PHY802.11b-TX-POWER-2MBPS
Transmission Power at 6 Mbps	Subnet, Interface	PHY802.11b-TX-POWER-6MBPS
Transmission Power at 11 Mbps	Subnet, Interface	PHY802.11b-TX-POWER-11MBPS
Receive Sensitivity at 1 Mbps	Subnet, Interface	PHY802.11b-RX-SENSITIVITY-1MBPS
Receive Sensitivity at 2 Mbps	Subnet, Interface	PHY802.11b-RX-SENSITIVITY-2MBPS
Receive Sensitivity at 6 Mbps	Subnet, Interface	PHY802.11b-RX-SENSITIVITY-6MBPS
Receive Sensitivity at 11 Mbps	Subnet, Interface	PHY802.11b-RX-SENSITIVITY-11MBPS
Estimated Directional Antenna Gain	Subnet, Interface	PHY802.11-ESTIMATED-DIRECTIONAL-ANTENNA-GAIN
Packet Reception Model	Subnet, Interface	PHY-RX-MODEL

Setting Parameters

- To enable Auto Rate Fallback, set **Enable Auto Rate Fallback** to *Yes*; otherwise set **Enable Auto Rate Fallback** to *No*.
- To use default BER tables, set **Packet Reception Model** to *PHY802.11a Reception Model*. To specify BER tables, set **Packet Reception Model** to *BER-based Reception Model* and configure the BER tables as described in Section 3.6.

3. If **Enable Auto Rate Fallback** is set to *Yes*, then set the dependent parameters listed in Table 3-10.

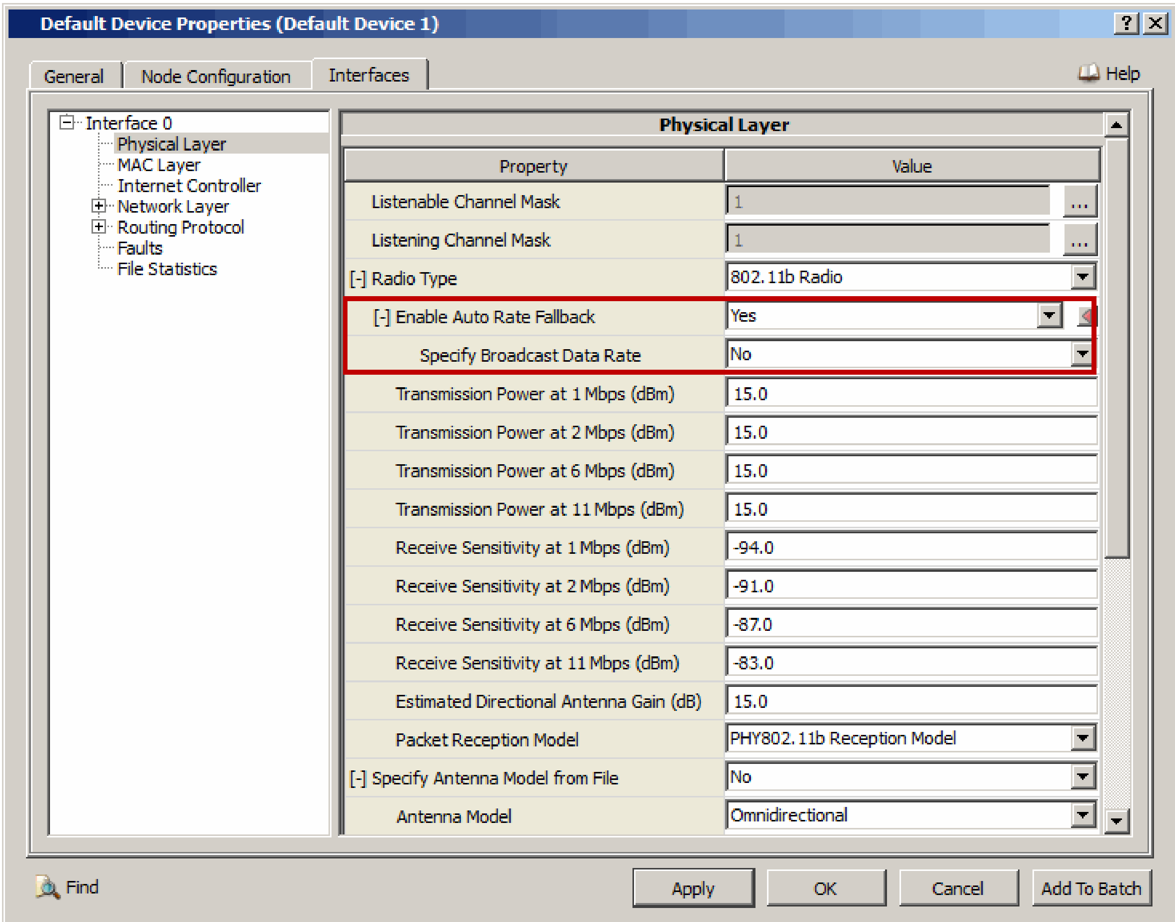

FIGURE 3-6. Setting Auto Rate Fallback Parameters

TABLE 3-10. Command Line Equivalent of Auto Rate Fallback Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Specify Broadcast Data Rate	Subnet, Interface	N/A

Setting Parameters

- To specify Broadcast data rate, set **Specify Broadcast Data Rate** to *Yes*, otherwise set **Specify Broadcast Data Rate** to *No*. Specify Broadcast Data Rate is a GUI-only parameter and does not have command line equivalent.

4. If **Specify Broadcast Data Rate** is set to *Yes*, then set the dependent parameters listed in Table 3-11.

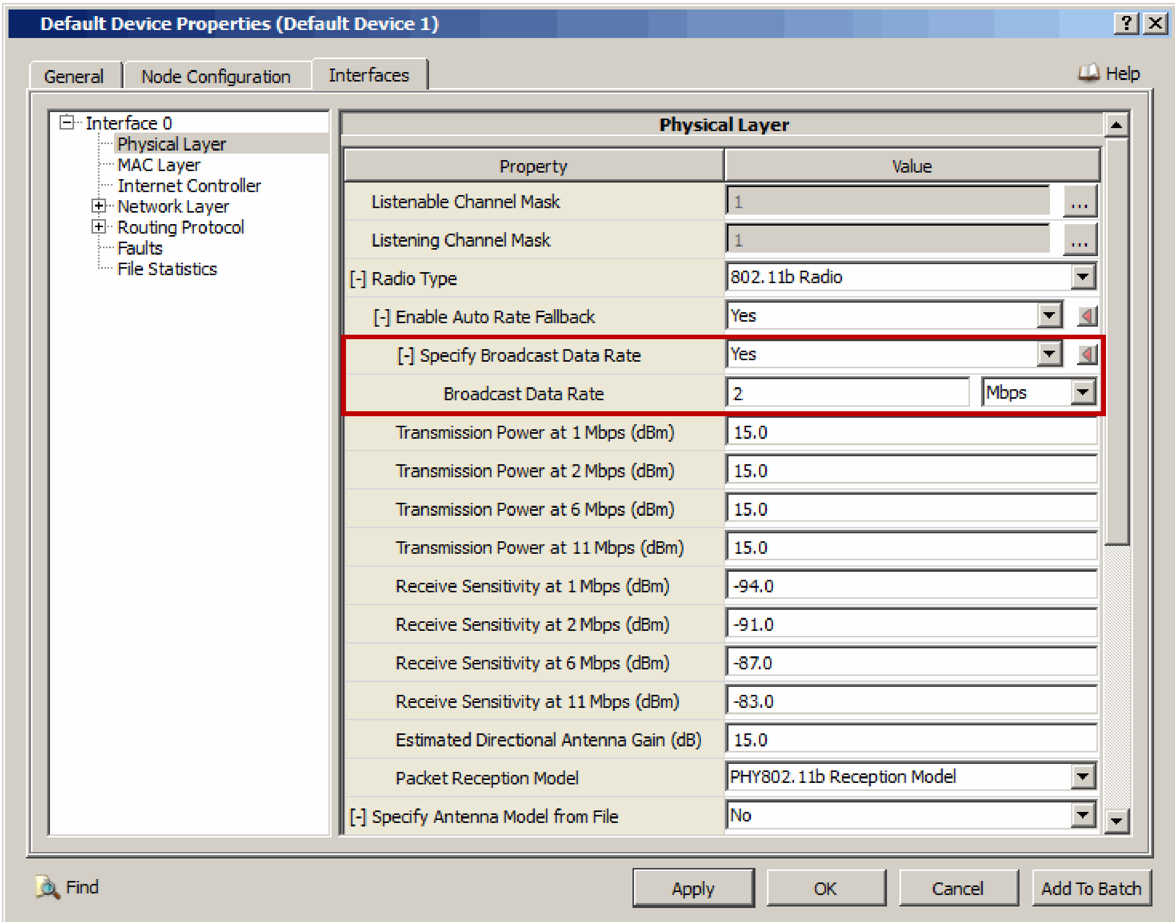

FIGURE 3-7. Setting Broadcast Data Rate Parameters

TABLE 3-11. Command Line Equivalent of Broadcast Data Rate Parameter

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Broadcast Data Rate	Subnet, Interface	`PHY802.11-DATA-RATE-FOR-BROADCAST`

5. If **Enable Auto Rate Fallback** is set to *No*, then set the dependent parameters listed in Table 3-12.

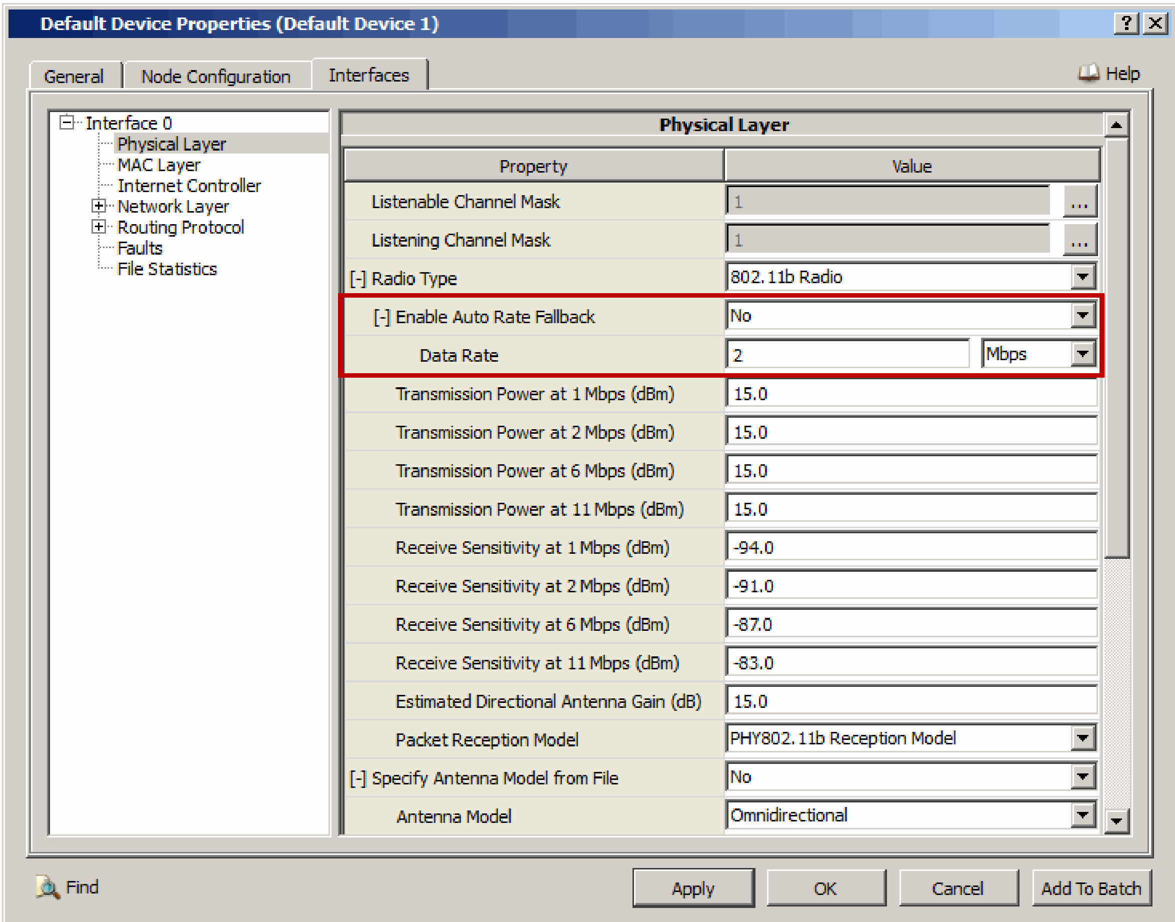

FIGURE 3-8. Setting Data Rate

TABLE 3-12. Command Line Equivalent of Enable Auto Rate Fallback Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Data Rate	Subnet, Interface	`PHY802.11-DATA-RATE`

Configuring Statistics Parameters

Statistics for the 802.11b PHY model can be collected at the global, node, subnet, and interface levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for 802.11b PHY, check the box labeled **PHY/Radio** in the appropriate properties editor.

TABLE 3-13. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
PHY/Radio	Global, Node, Subnet, Interface	`PHY-LAYER-STATISTICS`

3.2.4 Statistics

This section describes the file, database, and dynamic statistics of the 802.11b PHY model.

3.2.4.1 File Statistics

Table 3-14 shows the 802.11b PHY statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 3-14. 802.11b PHY Statistics

Statistic	Description
Signals transmitted (signals)	Number of signals transmitted
Signals detected (signals)	Number of signals detected by PHY
Signals locked (signals)	Number of signals locked on by PHY
Signals received with errors (signals)	Number of signals received with errors
Signals received with interference (signals)	Number of signals received with interference
Signals sent to mac (signals)	Number of signals sent to MAC
Time spent transmitting (seconds)	Time spent in transmitting signal
Time spent receiving (seconds)	Time spent in receiving signal
Average transmission delay (seconds)	Total average transmission delay
Utilization (percent/100)	Total utilization
Average signal power (dBm)	Total average signal power
Average interference (dBm)	Total average interference
Average pathloss (dB)	Total average pathloss

3.2.4.2 Database Statistics

In addition to the file statistics, the 802.11b PHY model also enters statistics in various scenario statistics database tables. Refer to *EXata Statistics Database User's Guide* for details.

3.2.4.3 Dynamic Statistics

No dynamic statistics are supported for the 802.11b PHY model.

3.2.5 References

1. IEEE Std 802.11b-1999, “Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Higher-Speed Physical Layer Extension in the 2.4 GHz Band.” September 16, 1999.

2. IEEE Std 802.11–1999, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications." March 18, 1999.

3. Bob O'Hara, Al Pet rick. The IEEE 802.11 Handbook: A Designers Companion. United States Of America:Standards Information Network IEEE Press.

3.3 802.11n PHY Model

3.3.1 Description

The IEEE 802.11 HT STA provides physical layer (PHY) features that can support a throughput of 100 Mbps and greater, as measured at the MAC data Service Access Point (SAP). An HT STA is also a Quality of Service (QoS) STA. The HT features are available to HT STAs associated with an HT Access Point (AP) in a Basic Service Set (BSS). A subset of the HT features is available for use between two HT STAs that are members of the same Independent Basic Service Set (IBSS).

The following PHY features distinguish an HT STA from a non-HT STA:

- Multiple Input, Multiple Output (MIMO) operation
- Spatial Multiplexing (SM)
- Spatial mapping (including transmit beamforming)
- Space-Time Block Coding (STBC)
- Low-Density Parity Check (LDPC) encoding
- Antenna SELection (ASEL).

The following PPDU formats are allowed:

- Non-HT format
- HT-mixed format
- HT-greenfield format.

The PPDUs may be transmitted with 20 MHz or 40 MHz bandwidth.

3.3.2 Features and Assumptions

This section describes the implemented features, omitted features, assumptions and limitations of the 802.11nPHY model.

3.3.2.1 Implemented Features

- Short GI operation
- MIMO

3.3.2.2 Omitted Features

- LDPC operation
- STBC operation
- PSMP Operation
- Sounding PPDUs
- Transmit beamforming
- Null Data Packet (NDP) sounding

3.3.2.3 Assumptions and Limitations

None.

3.3.3 Command Line Configuration

To select 802.11n PHY as the PHY model, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]  PHY-MODEL        PHY-802.11n
```

This scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

802.11n PHY Parameters

Table 3-15 lists the 802.11n PHY parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 3-15. 802.11n PHY Parameters

Parameter	Value	Description
PHY802.11n-NUM-ANTENNA-ELEMENTS *Optional* *Scope:* All	Integer *Range:* [1, 4] *Default:* 1	Specifies the number of antenna elements.
PHY802.11n-SHORT-GI-CAPABLE *Optional* *Scope:* All	List • YES • NO *Default:* NO	Enables the short guard interval capability.
PHY802.11n-TX-POWER *Optional* *Scope:* All	Real *Range:* > 0.0 *Default:* 20.0 *Unit:* dBm	Specifies the transmit power.
PHY802.11n-CHANNEL-BANDWIDTH *Optional* *Scope:* All	List: • 20MHz • 40MHz *Default:* 20MHZ	Specifies the channel bandwidth.
PHY802.11n-RX-SENSITIVITY-20MHz-MCS0 *Optional* *Scope:* All	Real *Default:* -82.0 *Unit:* dBm	Sets the receiver sensitivity at 20 MHz for MCS 0.
PHY802.11n-RX-SENSITIVITY-20MHz-MCS1 *Optional* *Scope:* All	Real *Default:* -79.0 *Unit:* dBm	Sets the receiver sensitivity at 20 MHz for MCS 1.

TABLE 3-15. 802.11n PHY Parameters (Continued)

Parameter	Value	Description
`PHY802.11n-RX-SENSITIVITY-20MHz-MCS2` *Optional* *Scope:* All	Real *Default:* `-77.0` *Unit:* dBm	Sets the receiver sensitivity at 20 MHz for MCS 2.
`PHY802.11n-RX-SENSITIVITY-20MHz-MCS3` *Optional* *Scope:* All	Real *Default:* `-74.0` *Unit:* dBm	Sets the receiver sensitivity at 20 MHz for MCS 3.
`PHY802.11n-RX-SENSITIVITY-20MHz-MCS4` *Optional* *Scope:* All	Real *Default:* `-70.0` *Unit:* dBm	Sets the receiver sensitivity at 20 MHz for MCS 4.
`PHY802.11n-RX-SENSITIVITY-20MHz-MCS5` *Optional* *Scope:* All	Real *Default:* `-66.0` *Unit:* dBm	Sets the receiver sensitivity at 20 MHz for MCS 5.
`PHY802.11n-RX-SENSITIVITY-20MHz-MCS6` *Optional* *Scope:* All	Real *Default:* `-65.0` *Unit:* dBm	Sets the receiver sensitivity at 20 MHz for MCS 6.
`PHY802.11n-RX-SENSITIVITY-20MHz-MCS7` *Optional* *Scope:* All	Real *Default:* `-64.0` *Unit:* dBm	Sets the receiver sensitivity at 20 MHz for MCS 7.
`PHY802.11n-RX-SENSITIVITY-40MHz-MCS0` *Optional* *Scope:* All	Real *Default:* `-79.0` *Unit:* dBm	Sets the receiver sensitivity at 40 MHz for MCS 0.
`PHY802.11n-RX-SENSITIVITY-40MHz-MCS1` *Optional* *Scope:* All	Real *Default:* `-76.0` *Unit:* dBm	Sets the receiver sensitivity at 40 MHz for MCS 1.

TABLE 3-15. 802.11n PHY Parameters (Continued)

Parameter	Value	Description
`PHY802.11n-RX-SENSITIVITY-40MHz-MCS2` *Optional* *Scope:* All	Real *Default:* `-74.0` *Unit:* dBm	Sets the receiver sensitivity at 40 MHz for MCS 2.
`PHY802.11n-RX-SENSITIVITY-40MHz-MCS3` *Optional* *Scope:* All	Real *Default:* `-71.0` *Unit:* dBm	Sets the receiver sensitivity at 40 MHz for MCS 3.
`PHY802.11n-RX-SENSITIVITY-40MHz-MCS4` *Optional* *Scope:* All	Real *Default:* `-67.0` *Unit:* dBm	Sets the receiver sensitivity at 40 MHz for MCS 4.
`PHY802.11n-RX-SENSITIVITY-40MHz-MCS5` *Optional* *Scope:* All	Real *Default:* `-63.0` *Unit:* dBm	Sets the receiver sensitivity at 40 MHz for MCS 5.
`PHY802.11n-RX-SENSITIVITY-40MHz-MCS6` *Optional* *Scope:* All	Real *Default:* `-62.0` *Unit:* dBm	Sets the receiver sensitivity at 40 MHz for MCS 6.
`PHY802.11n-RX-SENSITIVITY-40MHz-MCS7` *Optional* *Scope:* All	Real *Default:* `-61.0` *Unit:* dBm	Sets the receiver sensitivity at 40 MHz for MCS 7.
`PHY-RX-MODEL` *Required* *Scope:* All	List: • `PHY802.11n`	Specifies the packet reception model. For 802.11n PHY, `PHY-RX-MODEL` must be set to `PHY802.11n`.

3.3.4 GUI Configuration

To configure the 802.11n PHY parameters, perform the following steps:

1. Go to one of the following locations:

- To set properties for a specific wireless subnet, go to **Wireless Subnet Properties Editor > Physical Layer**.
- To set properties for a specific interface of a node, go to one of the following locations:
  - **Default Device Properties Editor > Interfaces > Interface # > Physical Layer**.

- **Interface Properties Editor > Interfaces > Interface # > Physical Layer**.

In this section, we show how to configure 802.11n PHY properties the Wireless Subnet Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **Radio Type** to *802.11n Radio* and set the dependent parameters listed in Table 3-16.

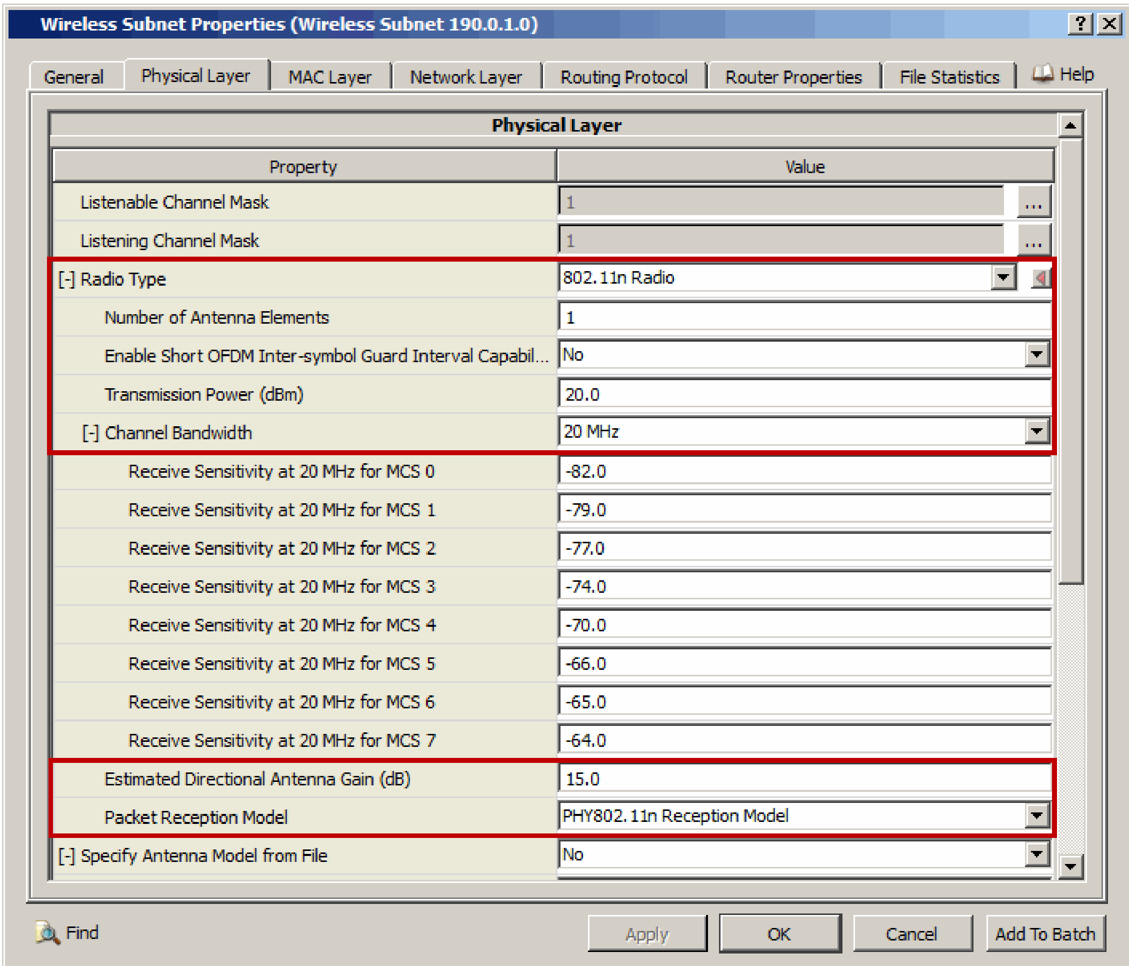

FIGURE 3-9. Setting 802.11n PHY Parameters

TABLE 3-16. Command Line Equivalent of 802.11n Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Number of Antenna Elements	Subnet, Interface	`PHY802.11n-NUM-ANTENNA-ELEMENTS`
Enable Short OFDM Inter-symbol Guard Interval Capability	Subnet, Interface	`PHY802.11n-SHORT-GI-CAPABLE`
Transmission Power	Subnet, Interface	`PHY802.11n-TX-POWER`
Channel Bandwidth	Subnet, Interface	`PHY802.11n-CHANNEL-BANDWIDTH`
Estimated Directional Antenna Gain	Subnet, Interface	`PHY802.11-ESTIMATED-DIRECTIONAL-ANTENNA-GAIN`
Packet Reception Mode	Subnet, Interface	`PHY-RX-MODEL`

3. If **Channel Bandwidth** is set to *20MHZ*, then set the dependent parameters listed in Table 3-17.

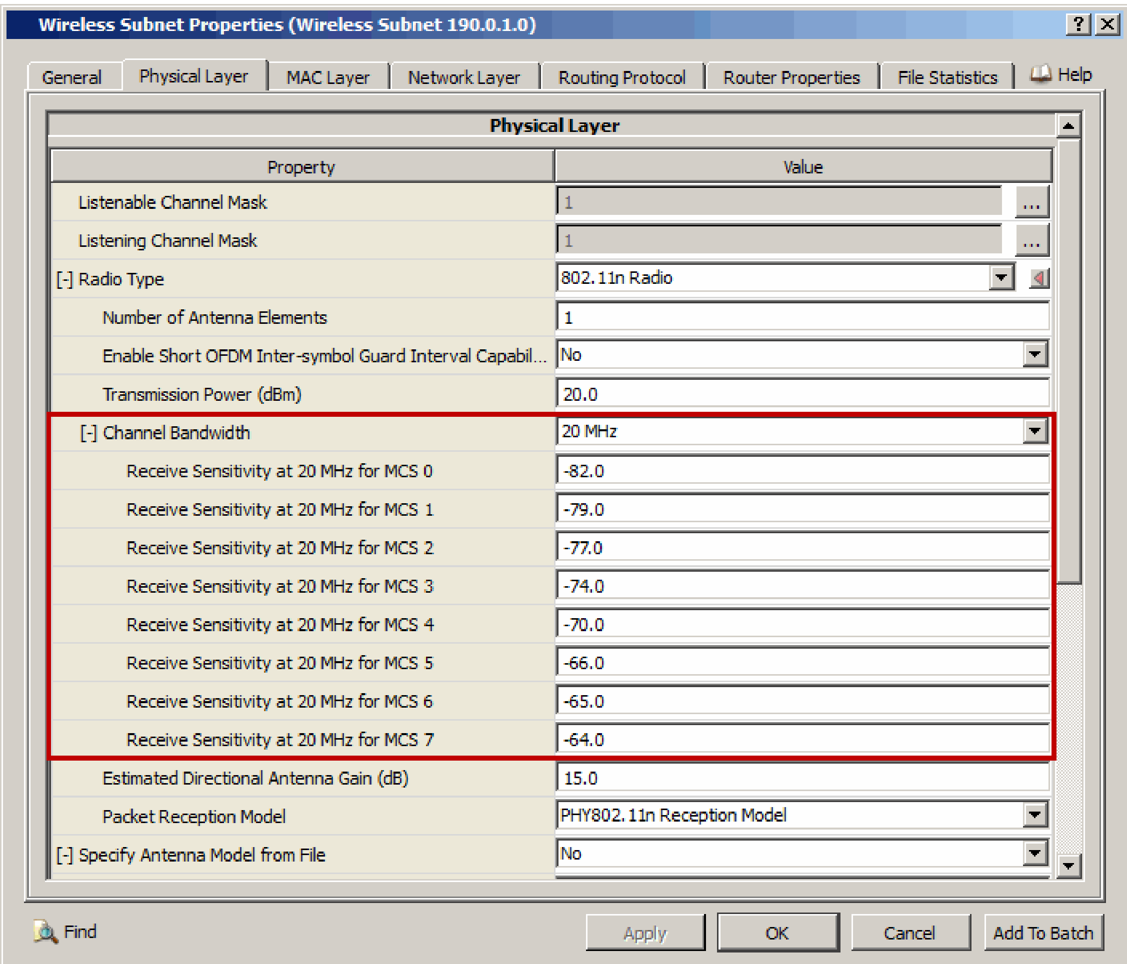

FIGURE 3-10. Setting 20 MHz Sensitivity Parameters

TABLE 3-17. Command Line Equivalent of 20 MHz Sensitivity Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Receive Sensitivity at 20 MHZ for MCS 0	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-20MHz-MCS0`
Receive Sensitivity at 20 MHZ for MCS 1	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-20MHz-MCS1`
Receive Sensitivity at 20 MHZ for MCS 2	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-20MHz-MCS2`
Receive Sensitivity at 20 MHZ for MCS 3	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-20MHz-MCS3`
Receive Sensitivity at 20 MHZ for MCS 4	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-20MHz-MCS4`
Receive Sensitivity at 20 MHZ for MCS 5	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-20MHz-MCS5`
Receive Sensitivity at 20 MHZ for MCS 6	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-20MHz-MCS6`
Receive Sensitivity at 20 MHZ for MCS 7	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-20MHz-MCS7`

4. If **Channel Bandwidth** is set to *40MHZ*, then set the dependent parameters listed in Table 3-17.

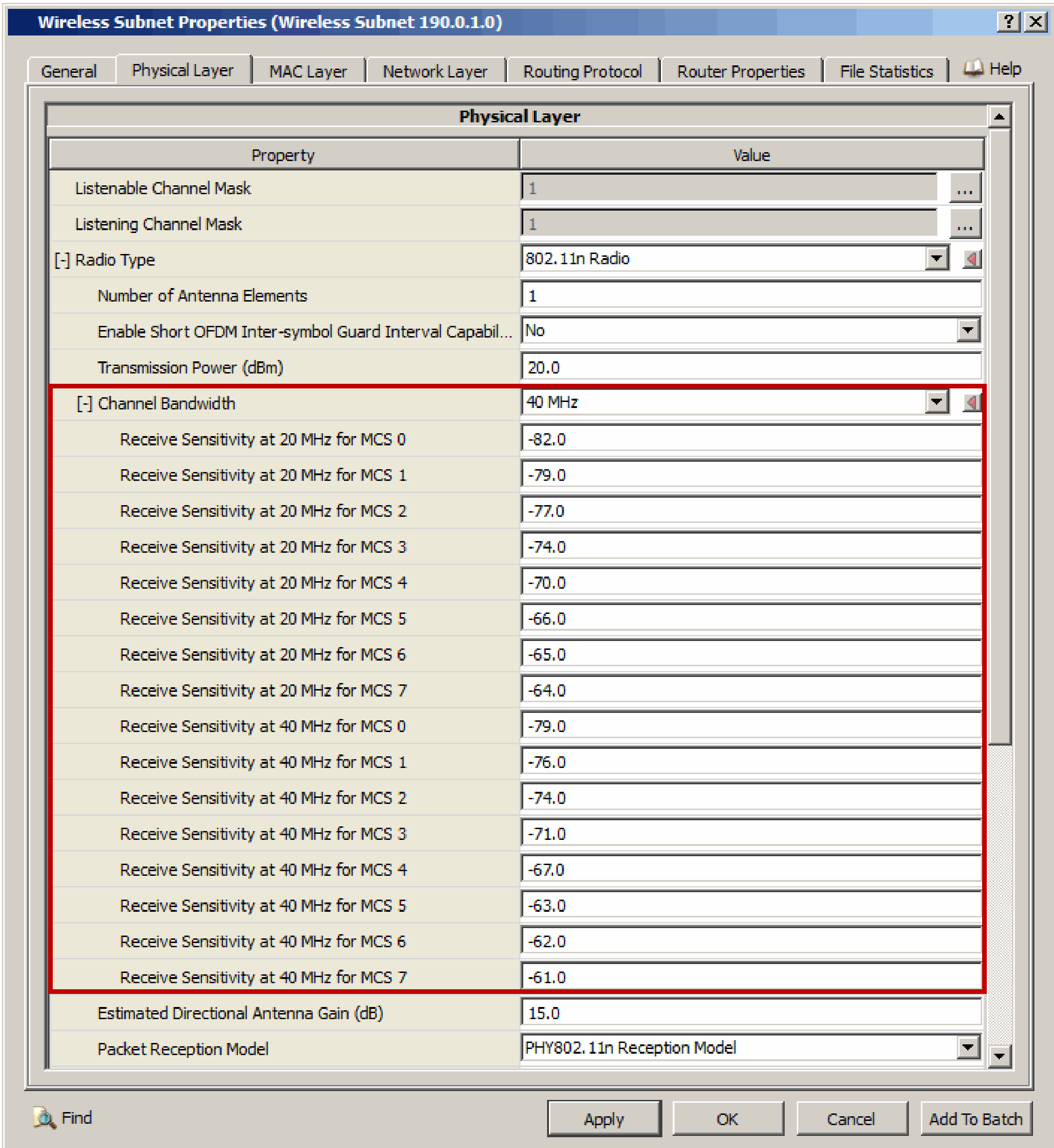

FIGURE 3-11. Setting 40 MHz Sensitivity Parameters

TABLE 3-18. Command Line Equivalent of 40 MHz Sensitivity Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Receive Sensitivity at 20 MHZ for MCS 0	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-20MHz-MCS0`
Receive Sensitivity at 20 MHZ for MCS 1	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-20MHz-MCS1`
Receive Sensitivity at 20 MHZ for MCS 2	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-20MHz-MCS2`
Receive Sensitivity at 20 MHZ for MCS 3	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-20MHz-MCS3`
Receive Sensitivity at 20 MHZ for MCS 4	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-20MHz-MCS4`
Receive Sensitivity at 20 MHZ for MCS 5	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-20MHz-MCS5`
Receive Sensitivity at 20 MHZ for MCS 6	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-20MHz-MCS6`
Receive Sensitivity at 20 MHZ for MCS 7	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-20MHz-MCS7`
Receive Sensitivity at 40 MHZ for MCS 0	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-40MHz-MCS0`
Receive Sensitivity at 40 MHZ for MCS 1	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-40MHz-MCS1`
Receive Sensitivity at 40 MHZ for MCS 2	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-40MHz-MCS2`
Receive Sensitivity at 40 MHZ for MCS 3	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-40MHz-MCS3`
Receive Sensitivity at 40 MHZ for MCS 4	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-40MHz-MCS4`
Receive Sensitivity at 40 MHZ for MCS 5	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-40MHz-MCS5`
Receive Sensitivity at 40 MHZ for MCS 6	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-40MHz-MCS6`
Receive Sensitivity at 40 MHZ for MCS 7	Subnet, Interface	`PHY802.11n-RX-SENSITIVITY-40MHz-MCS7`

3.3.5 Statistics

No statistics are generated for the 802.11n PHY model.

3.3.6 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the 802.11n PHY protocol. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/dot11n. Table 3-19 lists the sub-directory where each scenario is located.

TABLE 3-19. 802.1n PHY Scenarios Included in EXata

Name	Description
amsdu_test	Demonstrates communication from one STA to another STA with AMSDU aggregation.
ampdu_test	Demonstrates communication from one STA to another STA with AMPDU aggregation.
short_gi_test	Demonstrates throughput enhancement using short guard interval.
throughput_test	Demonstrates throughput enhancement using various antenna elements.
ad-hoc_test	Demonstrates 802.11n functionalities in ad-hoc mode.

3.3.7 References

- IEEE 802.11n–2009. “Enhancements for Higher Throughput.” 29 October, 2009.

3.4 Abstract PHY Model

3.4.1 Description

The Abstract PHY model is a simple radio model that supports either Signal-to-Noise Ratio (SNR) or Bit Error Rate (BER) based reception. It is not abstract in the mathematical sense; it still models all the signal transmissions and receptions. Rather, it is a simple flexible model that can be used to model various types of radios where a detailed model of the radio is not required.

3.4.2 Command Line Configuration

To specify Abstract PHY as the PHY model, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]  PHY-MODEL        PHY-ABSTRACT
```

The scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

Abstract PHY Parameters

Table 3-20 shows the Abstract PHY configuration parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 3-20. Abstract PHY Parameters

Parameter	Value	Description
`PHY-ABSTRACT-DATA-RATE` *Optional* *Scope:* All	Integer *Range:* > 0 *Default:* 2000000 *Unit:* bps	Specifies the data rate.
`PHY-ABSTRACT-BANDWIDTH` *Optional* Scope: All	Integer *Range:* > 0 *Default:* 2000000 *Unit:* Hz	Specifies the channel bandwidth.
`PHY-ABSTRACT-TX-POWER` *Optional* *Scope:* All	Real *Default:* 15.0 *Unit:* dBm	Specifies the transmission power.
`PHY-ABSTRACT-RX-SENSITIVITY` *Optional* *Scope:* All	Real *Range:* (see note) *Default:* -91.0 *Unit:* dBm	Specifies the minimum signal strength that can be sensed by the receiver. **Note:** `PHY-ABSTRACT-RX-SENSITIVITY` should be greater than the noise power.

TABLE 3-20. Abstract PHY Parameters (Continued)

Parameter	Value	Description
PHY-ABSTRACT-RX-THRESHOLD *Optional* *Scope:* All	Real *Default:* -81.0 *Unit:* dBm	Specifies the minimum strength of a signal that can be received.
PHY-RX-MODEL *Required* *Scope:* All	List: • BER-BASED • SNR-THRESHOLD-BASED	Specifies the packet reception model. See Section 3.6 for details of the BER-based reception model. See Section 3.8 for details of the SNR-based reception model.
PHY-LAYER-STATISTICS *Optional* Scope: All	List • YES • NO *Default:* NO	Indicates whether statistics are collected for the physical layer protocols, including Abstract PHY.

3.4.3 GUI Configuration

This section describes how to configure Abstract PHY model in the GUI.

Configuring Abstract PHY Model Parameters

To configure the Abstract PHY parameters, perform the following steps:

1. Go to one of the following locations:

- To set wireless subnet properties, go to **Wireless Subnet Properties Editor > Physical Layer**.
- To set properties a specific interface of a node, go to one of the following locations:
  - **Interface Properties Editor > Interfaces > Interface # > Physical Layer**.
  - **Default Device Properties Editor > Interfaces > Interface # > Physical Layer**.

In this section, we show how to configure Abstract PHY parameters for a specific interface using the Default Device Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **Radio Type** to *Abstract* and set the dependent parameters of the model, as listed in Table 3-21.

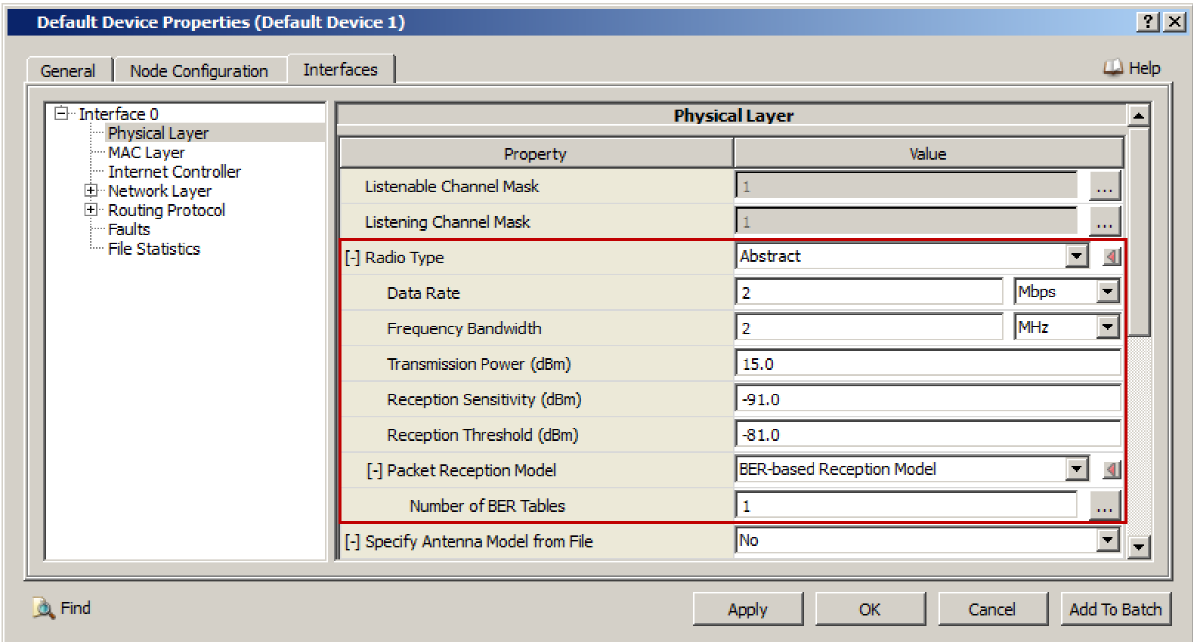

FIGURE 3-12. Setting Abstract PHY Parameters

TABLE 3-21. Command Line Equivalent of Abstract PHY Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Data Rate	Subnet, Interface	`PHY-ABSTRACT-DATA-RATE`
Frequency Bandwidth	Subnet, Interface	`PHY-ABSTRACT-BANDWIDTH`
Transmission Power (dBm)	Subnet, Interface	`PHY-ABSTRACT-TX-POWER`
Reception Sensitivity (dBm)	Subnet, Interface	`PHY-ABSTRACT-RX-SENSITIVITY`
Reception Threshold (dBm)	Subnet, Interface	`PHY-ABSTRACT-RX-THRESHOLD`
Packet Reception Model	Subnet, Interface	`PHY-RX-MODEL`

3. If **Packet Reception Model** is set to *BER-based Reception Model.* User can specify the BER files. Set the dependent parameter as listed in Table 3-22.

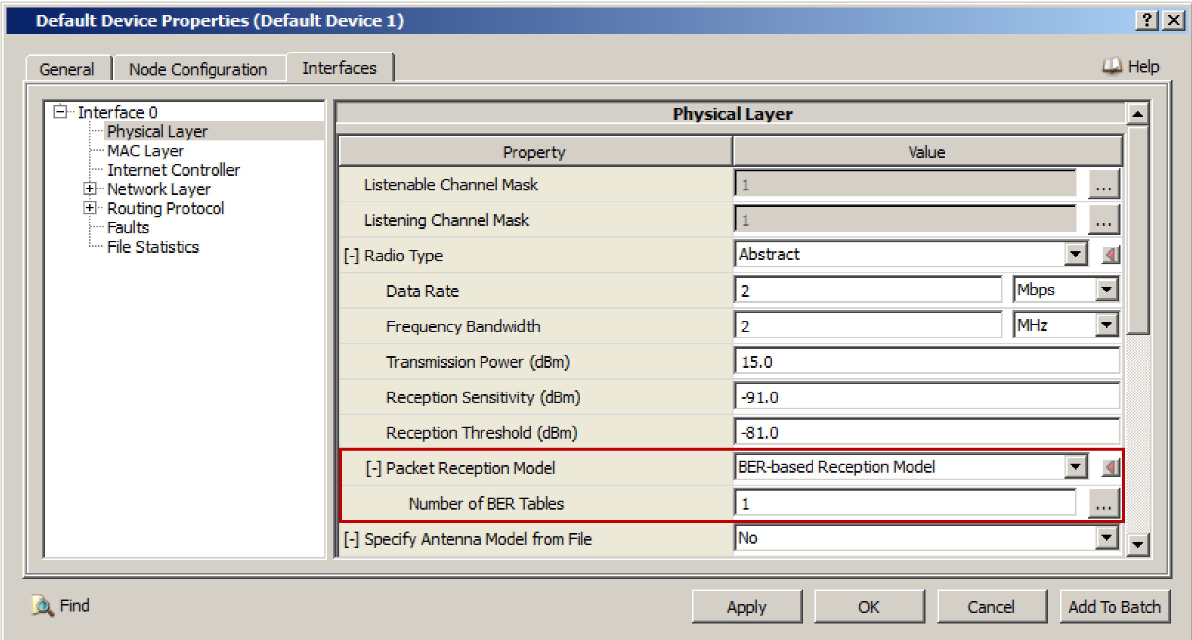

FIGURE 3-13. Setting Packet Reception Model

TABLE 3-22. Command Line Equivalent of Packet Reception Model Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Number of BER Tables	Subnet, Interface	`NUM-PHY-RX-BER-TABLE-ABSTRACT`

Setting Parameters

- Set **Number of BER Tables to the desired values as shown in** Figure 3-13.

4. To configure the BER table properties, do the following:

a. Click the **Open Array Editor** button in the **Value** column. This opens the Array Editor (Figure 3-14).

b. Set the parameters listed in Table 3-23 by clicking the **Select File** button and choose a file for each BER table index.

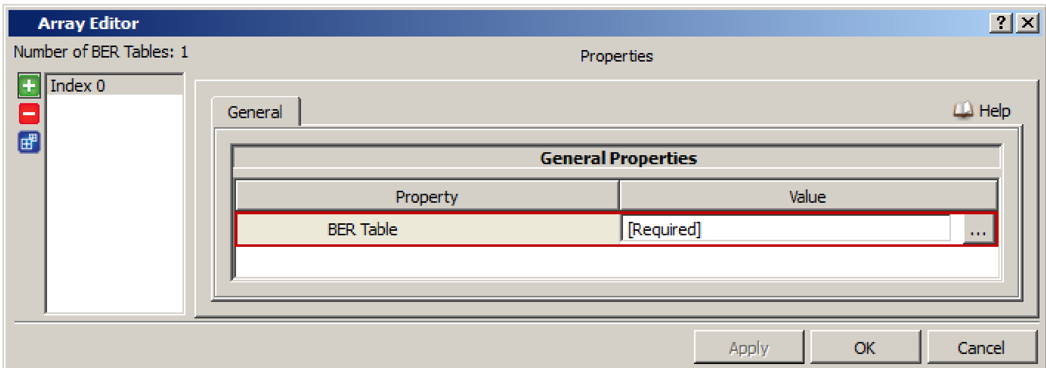

FIGURE 3-14. Setting BER Table Parameters

TABLE 3-23. Command Line Equivalent of BER Table Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
BER Table	Subnet, Interface	`PHY-RX-BER-TABLE-FILE`

5. If **Packet Reception Model** is set to *SNR-based Reception Model*. User need not to explicitly define the BER files, default BER files will be used. Set the dependent parameter as listed in Table 3-22.

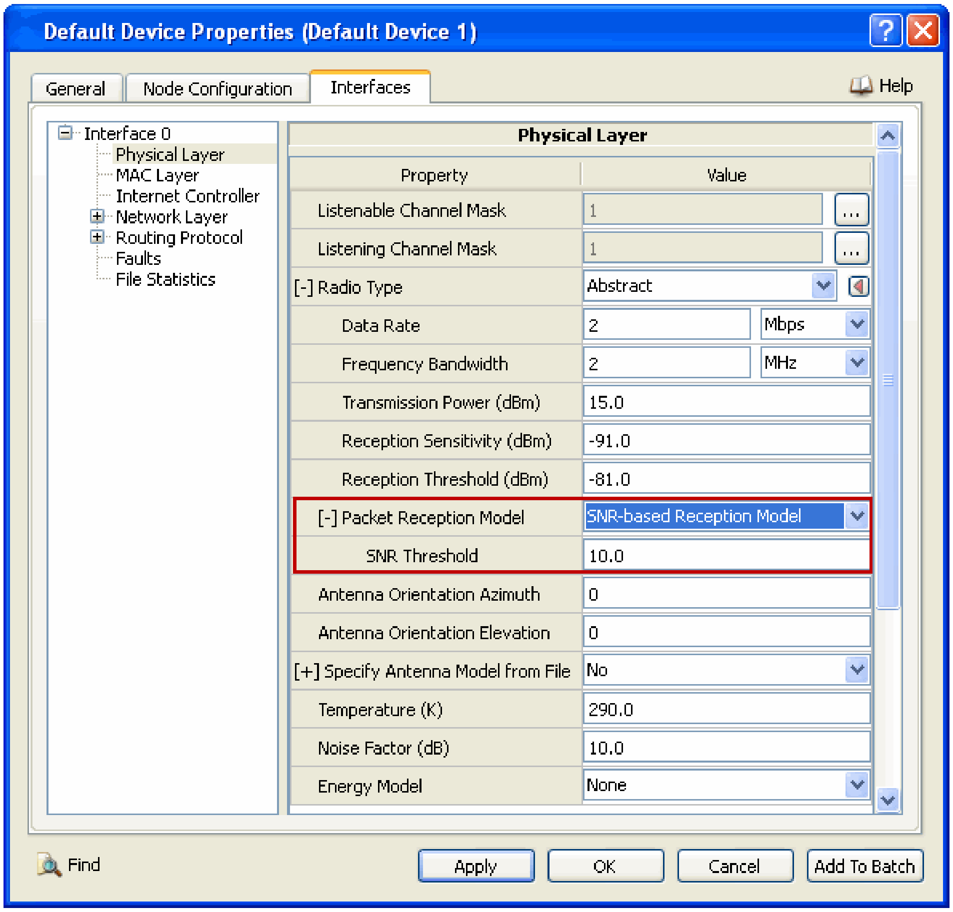

FIGURE 3-15. Setting Packet Reception Model

TABLE 3-24. Command Line Equivalent of Packet Reception Model Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
SNR Threshold	Interface, Subnet	`PHY-ABSTRACT-RX-THRESHOLD`

Configuring Statistics Parameters

Statistics for Abstract PHY can be collected at the global, node, subnet, and interface levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for Abstract PHY, check the box labeled **PHY/Radio** in the appropriate properties editor.

TABLE 3-25. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
PHY/Radio	Global, Node, Subnet, Interface	`PHY-LAYER-STATISTICS`

3.4.4 Statistics

This section describes the file, database, and dynamic statistics of the Abstract PHY model.

3.4.4.1 File Statistics

Table 3-26 shows the Abstract PHY statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 3-26. Abstract PHY Statistics

Statistic	Description
Signals transmitted (signals)	Number of signals transmitted
Signals detected (signals)	Number of signals detected by PHY
Signals locked (signals)	Number of signals locked on by PHY
Signals received with errors (signals)	Number of signals received with errors
Signals received with interference (signals)	Number of signals received with interference
Signals sent to mac (signals)	Number of signals sent to MAC
Time spent transmitting (seconds)	Time spent in transmitting signal
Time spent receiving (seconds)	Time spent in receiving signal
Average transmission delay (seconds)	Total average transmission delay
Utilization (percent/100)	Total utilization
Average signal power (dBm)	Total average signal power
Average interference (dBm)	Total average interference
Average pathloss (dB)	Total average pathloss

3.4.4.2 Database Statistics

In addition to the file statistics, the Abstract PHY model also enters statistics in various scenario statistics database tables. Refer to *EXata Statistics Database User's Guide* for details.

3.4.4.3 Dynamic Statistics

The following dynamic statistics are enabled for the Abstract PHY model (refer to Chapter 6 of *EXata User's Guide* for details of viewing dynamic statistics in the GUI during the simulation):

- Number of Signals Transmitted
- Number of Signals Detected
- Number of Signals Locked onto
- Number of Signals Received with Errors
- Number of Signals Forwarded to MAC layer

- Signal-to-Noise Ratio (dB)
- Energy Consumption (mWhr)

3.5 Antenna Models

3.5.1 Description

EXata supports four standard antenna models: Omni-directional, Switched-beam, Steerable and Patterned. In addition, users can define custom antenna models.

Omnidirectional Antenna Model

The Omnidirectional antenna is the basic antenna which yields the same antenna gain irrespective of the direction of the transmitted or received signal.

Patterned Antenna Model

The Patterned antenna transmits or receives according to a particular pattern specified in the pattern file. Antenna pattern files can be specified in Open-ASCII (2-D and 3-D) and NSMA formats, in addition to the traditional format.

Switched-beam Antenna Model

The Switched-beam antenna is a special type of patterned antenna. A patterned antenna has different gains in different directions. The values of the gain in different directions follow a gain pattern. A Switched-beam antenna can utilize multiple antenna patterns and switches the pattern according to direction of arrival or transmission. Antenna pattern files can be specified in Open-ASCII (2D and 3D) and NSMA formats, in addition to the traditional format.

Steerable Antenna Model

The Steerable antenna is a special type of patterned antenna. A patterned antenna has different gains in different directions. The values of the gain in different directions follow a gain pattern. The Steerable antenna steers the boresight of the antenna according to the direction of arrival. Antenna pattern files can be specified in Open-ASCII (2D and 3D) and NSMA formats, in addition to the traditional format.

Custom Antenna Models

Users can define custom antenna models in an Antenna Models file. Each antenna model definition comprises a model name followed by the parameters for that model. These parameters define the characteristics of the antenna. The model's name is used in the scenario configuration (.config) file to assign an antenna model to an interface, in which case all parameters associated with that model apply to the interface.

3.5.2 Features and Assumptions

This section describes the implemented features, omitted features, assumptions and limitations of the antenna models.

3.5.2.1 Implemented Features

- Traditional radiation pattern format, NSMA and Open-ASCII file formats are parsed to use them in EXata.

3.5.2.2 Omitted Features

None.

3.5.2.3 Assumptions and Limitations

None.

3.5.3 Command Line Configuration

This section describes how to configure the general antenna parameters that are applicable for all antenna models and parameters specific to each antenna model.

3.5.3.1 Configuring Standard Antenna Models

To specify the Omnidirectional antenna model, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>] ANTENNA-MODEL     OMNIDIRECTIONAL
```

To specify the Steerable antenna model, include the following parameter in the scenario configuration file:

```
[<Qualifier>] ANTENNA-MODEL     STEERABLE
```

To specify the Switched-beam antenna model, include the following parameter in the scenario configuration file:

```
[<Qualifier>] ANTENNA-MODEL     SWITCHED-BEAM
```

To specify the Patterned antenna model, include the following parameter in the scenario configuration file:

```
[<Qualifier>] ANTENNA-MODEL      PATTERNED
```

Note: The scope of the parameter `ANTENNA-MODE` can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

The default value of the parameter `ANTENNA-MODE` is `OMNIDIRECTIONAL`.

For the Omnidirectional antenna model, set the parameters listed in Table 3-27.

For the Steerable, Switched-beam, and Patterned antenna models, set the parameters listed in Table 3-27 and Table 3-28.

See Section 1.2.1.3 for a description of the format used for the parameter tables.

TABLE 3-27. General Parameters for Standard Antenna Models

Parameter Name	Value	Description
`ANTENNA-GAIN` Optional *Scope:* All	Real *Default:* `0.0` *Unit:* dBi	Antenna gain relative to an isotropic antenna. This parameter is used to specify the antenna gain for an omni-directional antenna. For directional antennas, the gain is specified in antenna pattern files.
`ANTENNA-HEIGHT` Optional *Scope:* All	Real *Range:* ≥ `0` *Default:* `1.5` *Unit:* meters	Height above the ground that the antenna is installed. The antenna height affects the propagation loss. The higher the antenna, the lower is the signal attenuation during propagation.
`ANTENNA-EFFICIENCY` Optional *Scope:* All	Real *Default:* `0.8`	Efficiency of the antenna. Antenna efficiency is the ratio of the power radiated into space to the power accepted from the source. The lower the wasted power, the higher is the efficiency of the antenna.
`ANTENNA-MISMATCH-LOSS` Optional *Scope:* All	Real *Default:* `0.3` *Unit:* dB	Loss caused by the mismatch between the antenna and the cable.
`ANTENNA-CABLE-LOSS` Optional *Scope:* All	Real *Default:* `0.0` *Unit:* dB	Antenna cable loss. This is a function of the cable type and the distance between the antenna and the transmitter/receiver. This value is typically in the range of 0 to several tens of dB.
`ANTENNA-CONNECTION-LOSS` Optional *Scope:* All	Real *Default:* `0.2` *Unit:* dB	Loss caused by the connectors between the transmitter/receiver and the cable, and between the cable and the antenna. In general, this value should be in the range of 0 to 1 dB.
`ANTENNA-OREINTATION-AZIMUTH` Optional *Scope:* All	Real *Default:* `0.0` *Unit:* degrees	Azimuth of the relative angle between the node orientation and antenna orientation. The absolute azimuth of the antenna orientation is the azimuth of the node orientation plus the value of this parameter.
`ANTENNA-OREINTATION-ELEVATION` Optional *Scope:* All	Real *Default:* `0.0` *Unit:* degrees	Elevation of the relative angle between the node orientation and antenna orientation. The absolute elevation of the antenna orientation is the elevation of the node orientation plus the value of this parameter.

Table 3-28 lists the additional parameters that must be set for the Steerable, Switched-beam, and Patterned antenna models.

TABLE 3-28. Additional Parameters for Directional Antenna Models

Parameter Name	Value	Description
`ANTENNA-PATTERN-STEERABLE-SET-REPEAT-ANGLE` Optional (see note) *Scope:* All	Integer *Default:* `360` *Unit:* degrees	Specifies the repeat angle for a steerable antenna in degrees. **Note:** This parameter is used only if `ANTENNA-MODEL` is set to `STEERABLE`.
`ANTENNA-PATTERN-TYPE` Optional *Scope:* All	List: • `ASCII2D` • `ASCII3D` • `NSMA` • `TRADITIONAL` *Default:* `TRADITIONAL`	Specifies the pattern type. `ASCII2D` : Open ASCII format for 2D antenna patterns. `ASCII3D` : Open ASCII format for 3D antenna patterns. `NSMA` : NSMA format for antenna patterns. `TRADITIONAL` : Native format for antenna
`ANTENNA-PATTERN-NUM-PATTERNS` Optional *Scope:* All	Integer *Range:* `> 0`	Specifies the number of antenna patterns. **Note:** It is recommended that this parameter be set to 1. **Note:** This parameter is required if `ANTENNA-PATTERN-TYPE` is set to `ASCII2D`, `ASCII3D`, or `NSMA`.
`ANTENNA-PATTERN-CONVERSION-PARAMETER` Optional *Scope:* All	Real *Unit:* dB	Specifies the conversion parameter (in dB) for the antenna pattern. **Note:** This parameter is required if `ANTENNA-PATTERN-TYPE` is set to `ASCII2D`, `ASCII3D`, or `NSMA`.
`ANTENNA-PATTERN-AZIMUTH-RESOLUTION` Optional *Scope:* All	Integer *Default:* `360`	Specifies the antenna azimuth angle resolution. The azimuth angle resolution indicates the number of parts into which the azimuth plane is divided. For example, if the value is 720, the azimuth plane is divided into 720 parts, and the azimuth angles are 0.0, 0.5, 1.0, 1.5, ..., 359.5, 360.0. **Note:** This parameter is used only if `ANTENNA-PATTERN-TYPE` is set to `ASCII2D`, `ASCII3D`, or `NSMA`.
`ANTENNA-PATTERN-ELEVATION-RESOLUTION` Optional *Scope:* All	Integer *Default:* `180`	Specifies the antenna elevation angle resolution. The elevation angle resolution indicates the number of parts into which the elevation plane is divided. For example, if the value is 360, the elevation plane is divided into 360 parts, and the elevation angles are 0.0, 0.5, 1.0, 1.5, ..., 179.5, 180.0. **Note:** This parameter is used only if `ANTENNA-PATTERN-TYPE` is set to `ASCII2D`, `ASCII3D`, or `NSMA`.

TABLE 3-28. Additional Parameters for Directional Antenna Models (Continued)

Parameter Name	Value	Description
`ANTENNA-AZIMUTH-PATTERN-FILE` Optional *Scope:* All	Filename	Specifies the name of the antenna azimuth pattern fie. The azimuth pattern file specifies the antenna gain at different azimuths. The format of the file is described in Section 3.5.3.1.1 (for traditional format) and in Section 3.5.3.1.3 (for Open ASCII 2D format). **Note:** This parameter is required if `ANTENNA-PATTERN-TYPE` is set to `ASCII2D` or `TRADITIONAL`.
`ANTENNA-ELEVATION-PATTERN-FILE` Optional *Scope:* All	Filename	Specifies the name of the antenna elevation pattern fie. The elevation pattern file specifies the antenna gain at different elevations. This file is used only for three-dimensional antenna patterns. The format of the file is described in Section 3.5.3.1.1 (for traditional format) and in Section 3.5.3.1.3 (for Open ASCII 2D format). **Note:** The number of patterns in the antenna elevation pattern file should be the same as the number of patterns in the antenna azimuth pattern file. **Note:** This parameter is used only if `ANTENNA-PATTERN-TYPE` is set to `ASCII2D` or `TRADITIONAL`.
`ANTENNA-PATTERN-PATTERN-FILE` Optional *Scope:* All	Filename	Specifies the name of the pattern fie. The format of the file is described in Section 3.5.3.1.2 (for Open ASCII 3D format) and in Section 3.5.3.1.4 (for NSMA format). **Note:** This parameter is required if `ANTENNA-PATTERN-TYPE` is set to `ASCII3D` or `NSMA`.

3.5.3.1.1 Format of Pattern Files in Traditional (Native) Format

This section describes the format of the pattern files that use the traditional (native) format.

The first line of the file specifies the number of patterns contained in the file and has the following format:

```
NUMBER-OF-RADIATION-PATTERNS   <num-patterns>
```

where

`<num-patterns>` Number of patterns in the file.

Each of the remaining lines specifies the antenna gain in a specific direction and has the following format:

```
<pattern-index>   <angle>   <gain>
```

where

`<pattern-index>`	Pattern number. This is an integer between 0 and `<num-patterns>` -1.
`<angle>`	Direction, in degrees. For the azimuth pattern file, 0 degrees corresponds to North. For the elevation pattern file, 0 degrees corresponds to the direction perpendicular to the antenna.
`<gain>`	Antenna gain in the specified direction, in dBi.

Example

The following lines show a segment of an antenna azimuth file:

```
NUMBER-OF-RADIATION-PATTERNS           10

0        0        15.56
0        1        15.55
0        2        15.54
0        3        15.52
...
0        357      15.52
0        358      15.54
0        359      15.55
1        0        15.56
1        1        15.55
1        2        15.52
...
9        357      15.52
9        358      15.54
9        359      15.55
```

3.5.3.1.2 Format of Pattern Files in Open ASCII 3D Format

This section describes the format of the pattern files that use the Open ASCII 3D format.

Each line of the file specifies the antenna gain in a specific direction and has the following format:

```
<theta> <phi> <gain>
```

where

`<theta>`	Elevation angle, in degrees.
`<phi>`	Azimuth angle, in degrees.
`<gain>`	Antenna gain in the specified direction, in dBi.

3.5.3.1.3 Format of Pattern Files in Open ASCII 2D Format

This section describes the format of the pattern files that use the Open ASCII 2D format.

Each line of the file specifies the antenna gain in a specific direction and has the following format:

```
<angle>   <gain>
```

where

`<angle>`	Angle, in degrees.
`<gain>`	Antenna gain in the specified direction, in dBi.

3.5.3.1.4 Format of Pattern Files in NSMA Format

Pattern files that use the NSMA format follow the NSMA standard, which is described in this section. In addition, the revised NSMA format WG16.99.050 is also supported.

An NSMA format pattern file has the following format:

```
<Antenna Manufacturer>
<Antenna Model Number>
<Comment>
<FCC ID Number>
<Reverse Pattern ID Number>
<Date of data>
<Manufacturer ID Number>
<Frequency Range>
<Mid-band Gain>
<Half-power Beam Width>
<Data-set_1>
<Data-set_2>
...
<Data-set_m>
```

where

`<Antenna Manufacturer>`	Name used to file data with the FCC.
`<Antenna Model Number>`	Antenna model number.
`<Comment>`	Comment for the antenna model.
`<FCC ID Number>`	ID number issued by the Common Carrier Branch of FCC.
`<Reverse Pattern ID Number>`	Reverse pattern FCC ID number. The reverse pattern is generally obtained by inserting the feed in an opposite manner in order to reverse the pattern.
`<Date of data>`	Date referenced on the published pattern.
`<Manufacturer ID Number>`	Reference number assigned by the antenna manufacturer.
`<Frequency Range>`	Full frequency range for which this pattern is valid. This should agree with the range specified in the printed pattern.

`<Mid-band Gain>`	Gain of the antenna model at mid-band.
`<Half-power Beam Width>`	Half-power beam width.
<Data-set$_i$>	i^{th} data set. The format of the data sets is described below.

Note: The first 10 lines (from <Antenna Manufacturer> to <Half-power Beam Width>) are required. However, the user can omit the information on any of these lines and enter `NONE` instead.

Each data set specifies a polarization and number of data points for that polarization on the first line. This is followed by the data points themselves. Each data point is entered on a line by itself and specifies an angle and the relative gain at that angle. The format of the i^{th} data set is:

```
<Polarization_i>      <N_i>
<Angle_i1>            <Relative-gain_i1>
<Angle_i2>            <Relative-gaini_12>
...
<Angle_iN_i>          <Relative-gain_iN_i>
```

where

<Polarization$_i$> Polarization of the i^{th} data set.

This can be `HH`, `HV`, `VH`, `VV`, `ELHH`, `ELHV`, or `ELVV`, where

- `HH`: Horizontal polarized port response to a horizontally polarized signal in the horizontal direction.
- `HV`: Horizontal polarized port response to a vertically polarized signal in the horizontal direction.
- `VV`: Vertical polarized port response to a vertically polarized signal in the horizontal direction
- `VH`: Vertical polarized port response to a horizontally polarized signal in the horizontal direction
- `ELHH`: Horizontal polarized port response to a horizontally polarized signal in the vertical direction
- `ELHV`: Horizontal polarized port response to a vertically polarized signal in the vertical direction
- `ELVV`: Vertical polarized port response to a vertically polarized signal in the vertical direction
- `ELVH`: Vertical polarized port response to a horizontally polarized signal in the vertical direction

Note: Specification of a data set with polarization `HH` is required. Specification of a data set with any other polarization is optional.

<N$_i$> Number of data points in the i^{th} data set.

`<Angle`$_{ij}$`>`	j^{th} angle in the i^{th} data set, in degrees.
	If `<Polarization`$_i$`>` is `HH`, `HV`, `VH`, or `VV`:
	`-180` ≤ `<Angle`$_{ij}$`>` ≤ `180`
	If `<Polarization`$_i$`>` is `ELHH`, `ELHV`, `ELVV`, or `ELVV`:
	`-90` ≤ `<Angle`$_{ij}$`>` ≤ `90`

`<Relative-gain`$_{ij}$`>`	Relative gain in the direction given by `<Angle`$_{ij}$`>`, in dB.

Example NSMA Format Pattern File

The following is an example of a pattern file in NSMA format:

```
NSMA-MANUFACTURE
D123
Antenna Pattern File in NSMA format
873
776
10/03/2011
N34
6525.0 - 6875.0
0
78888
HH   19
   -180.0   -29.1
   -37.0    -29.0
   -32.0    -26.0
   -19.0    -26.0
   -13.0    -22.2
   ...
   32.0     -26.0
   37.0     -29.0
   180.0    -29.1
HV  7
   -180.0   -33.7
   ...
   11.0     -33.6
   180.0    -33.7

VV  29
   -180.0   -29.6
   -98.0    -29.5
   -83.0    -23.3
   -51.0    -23.2
   ...
   83.0     -23.3
   98.0     -29.5
   180.0    -29.6
```

```
VH   7
   -180.0    -34.0
   -10.0     -33.9
   -8.0      -30.0
   0.0       -30.0
   8.0       -30.0
   10.0      -33.9
   180.0     -34.0
ELHH           0
```

3.5.3.2 Configuring Custom Antenna Models

To specify a custom antenna model, include the following parameters in the scenario configuration (.config) file:

```
ANTENNA-MODEL-CONFIG-FILE      <antenna-models-file>
[<Qualifier>] ANTENNA-MODEL    <model-name>
```

where

`<antenna-models-file>`	Name of the Antenna Models file. This file contains user-defined antenna models. The format of this file is described in Section 3.5.3.2.1
`<model-name>`	Value of any occurrence of parameter `ANTENNA-MODEL-NAME` in the Antenna Models file.

The scope of the parameter `ANTENNA-MODE` can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

To use a custom antenna model in a scenario, set the parameter `ANTENNA-MODEL` to the name of a custom antenna model (value of any occurrence of parameter `ANTENNA-MODEL-NAME` in the Antenna Models file). Parameters associated with the custom antenna model in the Antenna Models file will be used as the antenna parameters for that interface. If the parameters are also specified in the scenario configuration file, then they will override from the parameter values defined in the Antenna Models file.

Examples of Parameter Usage

The following lines show how to use custom antenna models in the scenario configuration (.config) file:

```
ANTENNA-MODEL-CONFIG-FILE      default.antenna-models
[1 2] ANTENNA-MODEL            NSMA-STEERABLE
[3 4] ANTENNA-MODEL            TRADITIONAL-PATTERNED
```

The above lines assume that the file default.antenna-models contains specifications of custom antenna models called `NSMA-STEERABLE` and `TRADITIONAL-PATTERNED`.

3.5.3.2.1 Format of the Antenna Models File

The Antenna Models file contains specifications of one or more custom antenna models. Each custom antenna model specification consists of a unique antenna model name (specified by the parameter `ANTENNA-MODEL-NAME`) followed by parameters that specify the characteristics of the antenna model.

The format of a custom antenna model specification is:

```
ANTENNA-MODEL-NAME        <Model-name>
<Parameter-name-1>        <Parameter-value-1>
<Parameter-name-2>        <Parameter-value-2>
...
<Parameter-name-n>        <Parameter-value-n>
```

where

`<Model-name>`	User-specified name of the antenna model. The antenna model name should be unique.
`<Parameter-name-i>`, `<Parameter-value-i>`	Parameter name and value pair. The parameters used in the specification of a custom antenna model are described in Table 3-29.

Table 3-29 describes the parameters for configuring a custom antenna model. These parameters are specified without any qualifiers or indices. Some of these parameters are mandatory, some are optional, and some are dependent on the values of other parameters. If an optional parameter is not specified for a model, then the value specified for that parameter in the scenario configuration (if any) is used. If the parameter is not specified in the scenario configuration file either, then the default value of the parameter is used.

TABLE 3-29. Parameters for Configuring Custom Antenna Models

Parameter Name	Value	Description
ANTENNA-MODEL-TYPE Required	List: • OMNIDIRECTIONAL • SWITCHED-BEAM • STEERABLE • PATTERNED	Specifies the type of the antenna model. OMNIDIRECTIONAL : Antenna gain is same in all directions. SWITCHED-BEAM : Switches the pattern according to direction of arrival or transmission. STEERABLE : Steers the boresight of the antenna according to the direction of arrival. PATTERNED : Transmits or receives according to a particular pattern specified in the pattern file.
ANTENNA-GAIN Optional	Real *Unit:* dBi	Antenna gain relative to an isotropic antenna. This parameter is used to specify the antenna gain for an omni-directional antenna. For directional antennas, the gain is specified in antenna pattern files.
ANTENNA-HEIGHT Optional	Real *Range:* ≥ 0 *Unit:* meters	Height above the ground that the antenna is installed. The antenna height affects the propagation loss. The higher the antenna, the lower is the signal attenuation during propagation.

TABLE 3-29. Parameters for Configuring Custom Antenna Models (Continued)

Parameter Name	Value	Description
`ANTENNA-EFFICIENCY` Optional	Real	Efficiency of the antenna. Antenna efficiency is the ratio of the power radiated into space to the power accepted from the source. The lower the wasted power, the higher is the efficiency of the antenna.
`ANTENNA-MISMATCH-LOSS` Optional	Real *Unit:* dB	Loss caused by the mismatch between the antenna and the cable.
`ANTENNA-CABLE-LOSS` Optional	Real *Unit:* dB	Antenna cable loss. This is a function of the cable type and the distance between the antenna and the transmitter/receiver. This value is typically in the range of 0 to several tens of dB.
`ANTENNA-CONNECTION-LOSS` Optional	Real *Unit:* dB	Loss caused by the connectors between the transmitter/receiver and the cable, and between the cable and the antenna. In general, this value should be in the range of 0 to 1 dB.
`ANTENNA-PATTERN-STEERABLE-SET-REPEAT-ANGLE` Optional (see note)	Integer *Unit:* degrees	Specifies the repeat angle for a steerable antenna in degrees. **Note:** This parameter is required if `ANTENNA-MODEL-TYPE` is set to `STEERABLE`.
`ANTENNA-PATTERN-TYPE` Optional (see note)	List: • `ASCII2D` • `ASCII3D` • `NSMA` • `TRADITIONAL`	Specifies the pattern type. `ASCII2D` : Open ASCII format for two-dimensional antenna patterns. `ASCII3D` : Open ASCII format for three-dimensional antenna patterns. `NSMA` : NSMA format for antenna patterns. `TRADITIONAL` : Native format for antenna patterns. **Note:** This parameter is required if `ANTENNA-MODEL-TYPE` is set to `STEERABLE`, `SWITCHED-BEAM`, or `PATTERNED`.
`ANTENNA-PATTERN-NUM-PATTERNS` Optional (see note)	Integer *Range:* `> 0`	Specifies the number of antenna patterns. **Note:** It is recommended that this parameter should be set to 1. **Note:** This parameter is required if `ANTENNA-PATTERN-TYPE` is set to `ASCII2D`, `ASCII3D`, or `NSMA`.
`ANTENNA-PATTERN-CONVERSION-PARAMETER` Optional (see note)	Real *Unit:* dB	Specifies the conversion parameter (in dB) for the antenna pattern. **Note:** This parameter is required if `ANTENNA-PATTERN-TYPE` is set to `ASCII2D`, `ASCII3D`, or `NSMA`.

TABLE 3-29. Parameters for Configuring Custom Antenna Models (Continued)

Parameter Name	Value	Description
ANTENNA-PATTERN-AZIMUTH-RESOLUTION Optional	Integer	Specifies the antenna azimuth angle resolution. The azimuth angle resolution indicates the number of parts into which the azimuth plane is divided. For example, if the value is 720, the azimuth plane is divided into 720 parts, and the azimuth angles are 0.0, 0.5, 1.0, 1.5, ..., 359.5, 360.0. **Note:** This parameter is used only if ANTENNA-PATTERN-TYPE is set to ASCII2D, ASCII3D, or NSMA.
ANTENNA-PATTERN-ELEVATION-RESOLUTION Optional	Integer	Specifies the antenna elevation angle resolution. The elevation angle resolution indicates the number of parts into which the elevation plane is divided. For example, if the value is 360, the elevation plane is divided into 360 parts, and the elevation angles are 0.0, 0.5, 1.0, 1.5, ..., 179.5, 180.0. **Note:** This parameter is used only if ANTENNA-PATTERN-TYPE is set to ASCII2D, ASCII3D, or NSMA.
ANTENNA-AZIMUTH-PATTERN-FILE Optional (see note)	Filename	Specifies the name of the antenna azimuth pattern fie. The azimuth pattern file specifies the antenna gain at different azimuths. The format of the file is described in Section 3.5.3.1.1 (for traditional format) and in Section 3.5.3.1.3 (for Open ASCII 2D format). **Note:** This parameter is required if ANTENNA-PATTERN-TYPE is set to ASCII2D or TRADITIONAL.
ANTENNA-ELEVATION-PATTERN-FILE Optional	Filename	Specifies the name of the antenna elevation pattern fie. The elevation pattern file specifies the antenna gain at different elevations. This file is used only for three-dimensional antenna patterns. The format of the file is described in Section 3.5.3.1.1 (for traditional format) and in Section 3.5.3.1.3 (for Open ASCII 2D format). **Note:** The number of patterns in the antenna elevation pattern file should be the same as the number of patterns in the antenna azimuth pattern file. **Note:** This parameter is used only if ANTENNA-PATTERN-TYPE is set to ASCII2D or TRADITIONAL.

TABLE 3-29. Parameters for Configuring Custom Antenna Models (Continued)

Parameter Name	Value	Description
ANTENNA-PATTERN-PATTERN-FILE Optional (see note)	Filename	Specifies the name of the pattern fie. The format of the file is described in Section 3.5.3.1.2 (for Open ASCII 3D format) and in Section 3.5.3.1.4 (for NSMA format). **Note:** This parameter is required if ANTENNA-PATTERN-TYPE is set to ASCII3D or NSMA

Example of Antenna Models File

The following is an example of an Antenna Models file which contains definitions of two custom models. The first model, called `NSMA-STEERABLE`, is a steerable antenna model which uses the NSMA file format for the pattern files. The second model, called `TRADITIONAL-PATTERNED`, is a patterned antenna model which uses the Traditional file format for pattern files.

```
# STEERABLE ANTENNA DEFINED IN THE NEW FORMAT USING NSMA FILE FORMAT

ANTENNA-MODEL-NAME                           NSMA-STEERABLE
ANTENNA-MODEL-TYPE                           STEERABLE
ANTENNA-GAIN                                 0.0
ANTENNA-HEIGHT                               1.5
ANTENNA-EFFICIENCY                           0.8
ANTENNA-MISMATCH-LOSS                        0.3
ANTENNA-CABLE-LOSS                           0.0
ANTENNA-CONNECTION-LOSS                      0.2
ANTENNA-PATTERN-NUM-PATTERNS                 6
ANTENNA-PATTERN-TYPE                         NSMA
ANTENNA-PATTERN-PATTERN-FILE                 default.nsm
ANTENNA-PATTERN-CONVERSION-PARAMETER         25
ANTENNA-PATTERN-STEERABLE-SET-REPEAT-ANGLE   60
ANTENNA-PATTERN-AZIMUTH-RESOLUTION           360
ANTENNA-PATTERN-ELEVATION-RESOLUTION         360

# PATTERNED ANTENNA DEFINED IN THE NEW FORMAT
# USING TRADITIONAL FILE FORMAT

ANTENNA-MODEL-NAME              TRADITIONAL-PATTERNED
ANTENNA-MODEL-TYPE              PATTERNED
ANTENNA-GAIN                    0.0
ANTENNA-HEIGHT                  1.5
ANTENNA-EFFICIENCY              0.8
ANTENNA-MISMATCH-LOSS           0.3
ANTENNA-CABLE-LOSS              0.0
ANTENNA-CONNECTION-LOSS         0.2
ANTENNA-PATTERN-TYPE            TRADITIONAL
ANTENNA-AZIMUTH-PATTERN-FILE    default.antenna-azimuth
```

3.5.4 GUI Configuration

This section describes how to configure antenna models in the GUI. Section 3.5.4.1 describes how to configure the standard antenna models (Omnidirectional, Switched-beam, Standard, and Patterned). Section 3.5.4.2 describes how to configure custom antenna models.

3.5.4.1 Configuring Standard Antenna Models

To configure the standard antenna models (Omnidirectional, Switched-beam, Standard, and Patterned), perform the following steps:

1. Go to one of the following locations:
   - To set properties for a specific wireless subnet, go to **Wireless Subnet Properties Editor > Physical Layer**.
   - To set properties for a specific interface of a node, go to one of the following locations:
     - **Default Device Properties Editor > Interfaces > Interface # > Physical Layer**.
     - **Interface Properties Editor > Interfaces > Interface # > Physical Layer**.

   In this section, we show how to configure antenna for a specific interface using the Wireless Subnet Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **Specify Antenna Model from File** to *No* and set the parameters listed in Table 3-30.

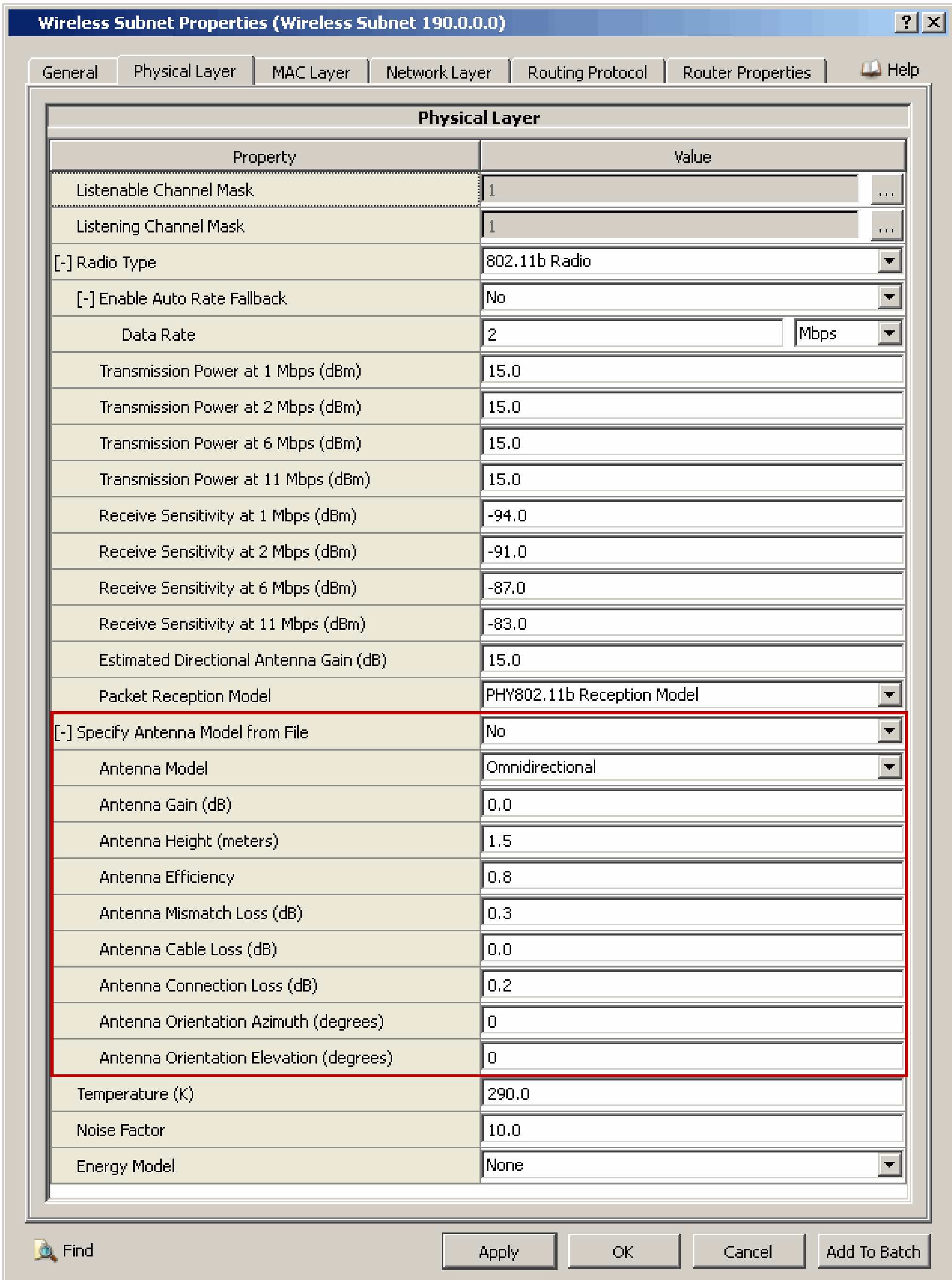

FIGURE 3-16. Setting General Antenna Parameters

TABLE 3-30. Command Line Equivalent of General Antenna Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Antenna Model	Subnet, Interface	`ANTENNA-MODEL`
Antenna Gain	Subnet, Interface	`ANTENNA-GAIN`
Antenna Height	Subnet, Interface	`ANTENNA-HEIGHT`
Antenna Efficiency	Subnet, Interface	`ANTENNA-EFFICIENCY`
Antenna Mismatch Loss	Subnet, Interface	`ANTENNA-MISMATCH-LOSS`
Antenna Cable Loss	Subnet, Interface	`ANTENNA-CABLE-LOSS`
Antenna Connection Loss	Subnet, Interface	`ANTENNA-CONNECTION-LOSS`
Antenna Orientation Azimuth	Subnet, Interface	`ANTENNA-OREINTATION-AZIMUTH`
Antenna Orientation Elevation	Subnet, Interface	`ANTENNA-ORIENTATION-ELEVATION`

3. If **Antenna Model** is set to *Steerable*, then set the dependent parameters listed in Table 3-31.

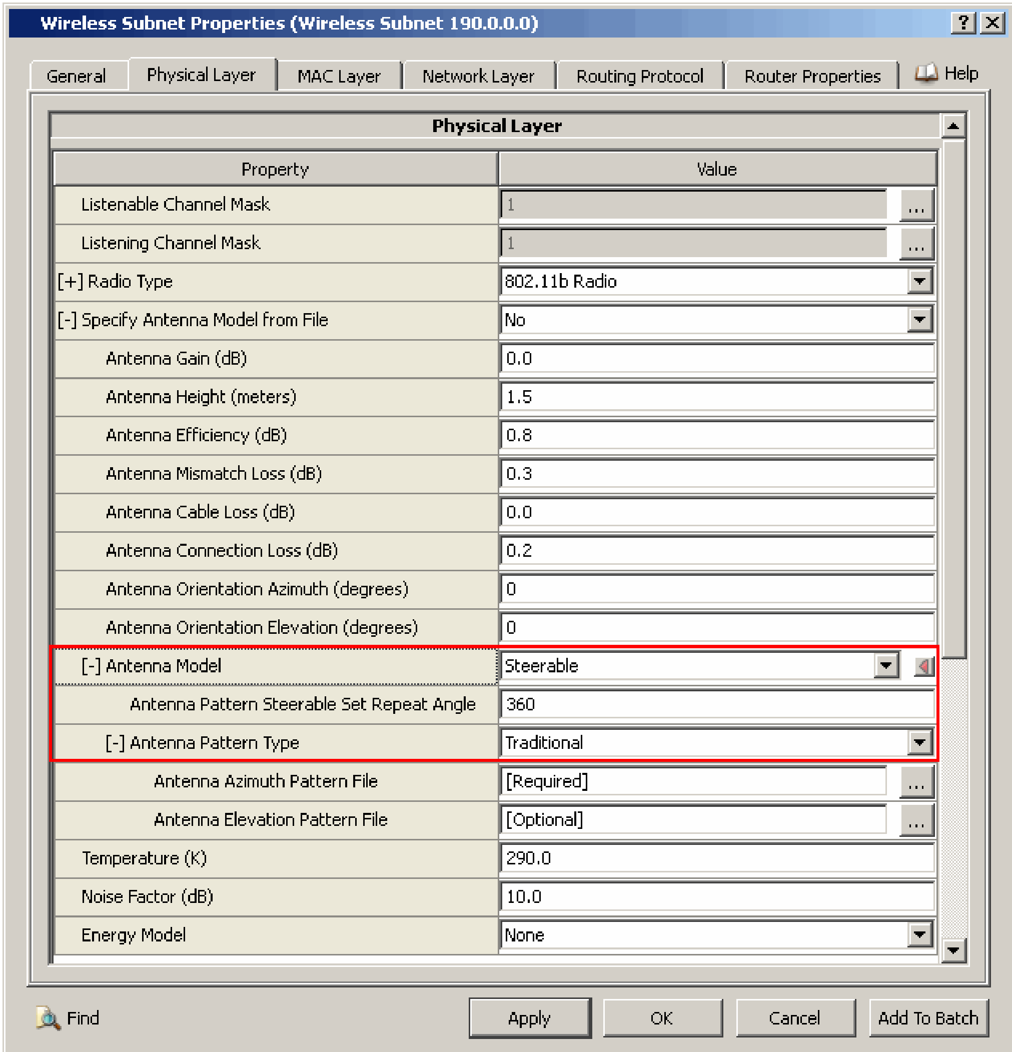

FIGURE 3-17. Setting Steerable Antenna Model Parameters

TABLE 3-31. Command Line Equivalent of Steerable Antenna Model Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Antenna Pattern Steerable Set Repeat Angle	Subnet, Interface	`ANTENNA-PATTERN-STEERABLE-SET-REPEAT-ANGLE`
Antenna Pattern Type	Subnet, Interface	`ANTENNA-PATTERN-TYPE`

Setting Parameters

- Select the antenna pattern by setting **Antenna Pattern Type** to *Traditional*, *Ascii2d*, *Ascii3d*, or *Nsma*.

4. If **Antenna Pattern Type** is set to *Traditional*, then set the dependent parameters listed in Table 3-32.

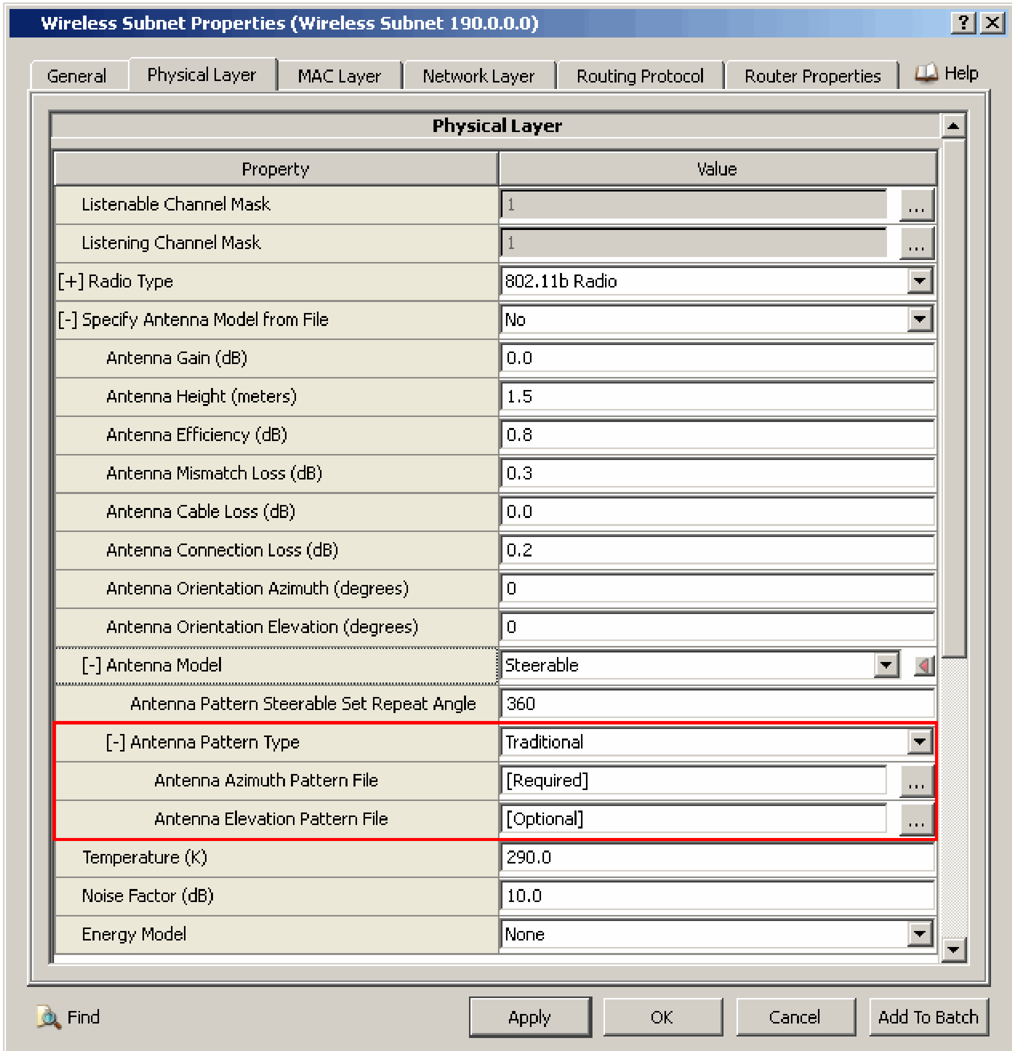

FIGURE 3-18. Setting Traditional Pattern Files

TABLE 3-32. Command Line Equivalent of Traditional Pattern File Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Antenna Azimuth Pattern File	Subnet, Interface	`ANTENNA-AZIMUTH-PATTERN-FILE`
Antenna Elevation Pattern File	Subnet, Interface	`ANTENNA-ELEVATION-PATTERN-FILE`

Setting Parameters

- Set **Antenna Azimuth Pattern File** and (optionally) **Antenna Azimuth Pattern File** to the names of the azimuth and antenna pattern files, respectively. See Section 3.5.3.1.1 for the format of these files.

5. If **Antenna Pattern Type** is set to *Ascii2d*, then set the dependent parameters listed in Table 3-33.

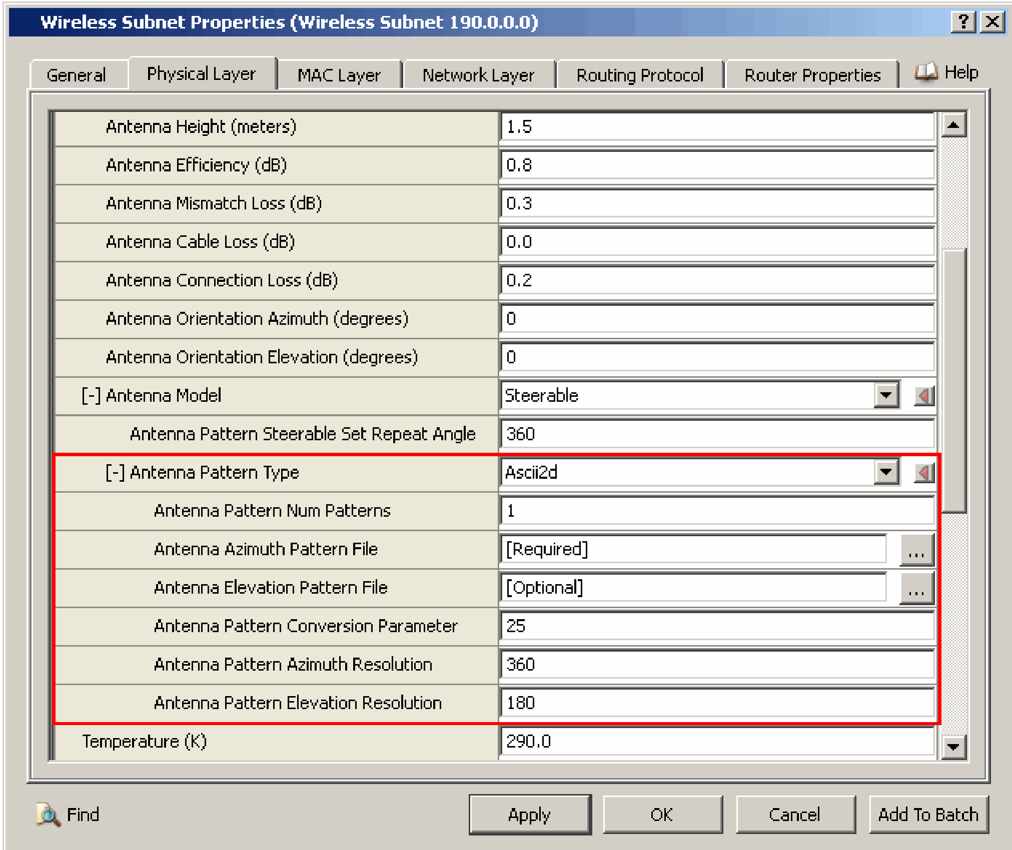

FIGURE 3-19. Setting ASCII 2D Pattern Parameters

TABLE 3-33. Command Line Equivalent of ASCII 2D Pattern Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Antenna Pattern Num Patterns	Subnet, Interface	`ANTENNA-PATTERN-NUM-PATTERNS`
Antenna Azimuth Pattern File	Subnet, Interface	`ANTENNA-AZIMUTH-PATTERN-FILE`
Antenna Elevation Pattern File	Subnet, Interface	`ANTENNA-ELEVATION-PATTERN-FILE`
Antenna Pattern Conversion Parameter	Subnet, Interface	`ANTENNA-PATTERN-CONVERSION-PARAMETER`
Antenna Pattern Azimuth Resolution	Subnet, Interface	`ANTENNA-PATTERN-AZIMUTH-RESOLUTION`
Antenna Pattern Elevation Resolution	Subnet, Interface	`ANTENNA-PATTERN-ELEVATION-RESOLUTION`

Setting Parameters

- Set **Antenna Azimuth Pattern File** and (optionally) **Antenna Azimuth Pattern File** to the names of the azimuth and antenna pattern files, respectively. See Section 3.5.3.1.2 for the format of these files.

6. If **Antenna Pattern Type** is set to *Ascii3d*, then set the dependent parameters listed in Table 3-34.

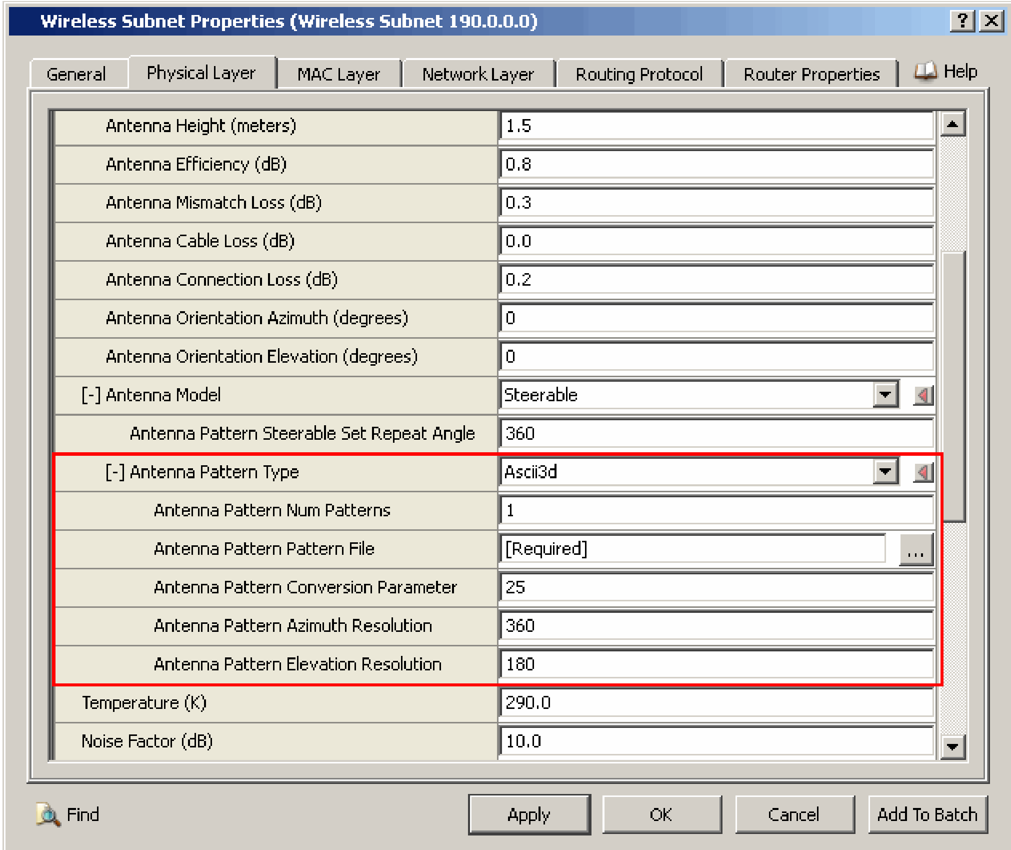

FIGURE 3-20. Setting ASCII 3D Pattern Parameters

TABLE 3-34. Command Line Equivalent of ASCII 3D Pattern Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Antenna Pattern Num Patterns	Subnet, Interface	`ANTENNA-PATTERN-NUM-PATTERNS`
Antenna Pattern Pattern File	Subnet, Interface	`ANTENNA-PATTERN-PATTERN-FILE`
Antenna Pattern Conversion Parameter	Subnet, Interface	`ANTENNA-PATTERN-CONVERSION-PARAMETER`
Antenna Pattern Azimuth Resolution	Subnet, Interface	`ANTENNA-PATTERN-AZIMUTH-RESOLUTION`
Antenna Pattern Elevation Resolution	Subnet, Interface	`ANTENNA-PATTERN-ELEVATION-RESOLUTION`

Setting Parameters

- Set **Antenna Pattern Pattern File** to the name of the pattern file, respectively. See Section 3.5.3.1.3 for the format of this file.

7. If **Antenna Pattern Type** is set to *Nsma*, then set the dependent parameters listed in Table 3-35.

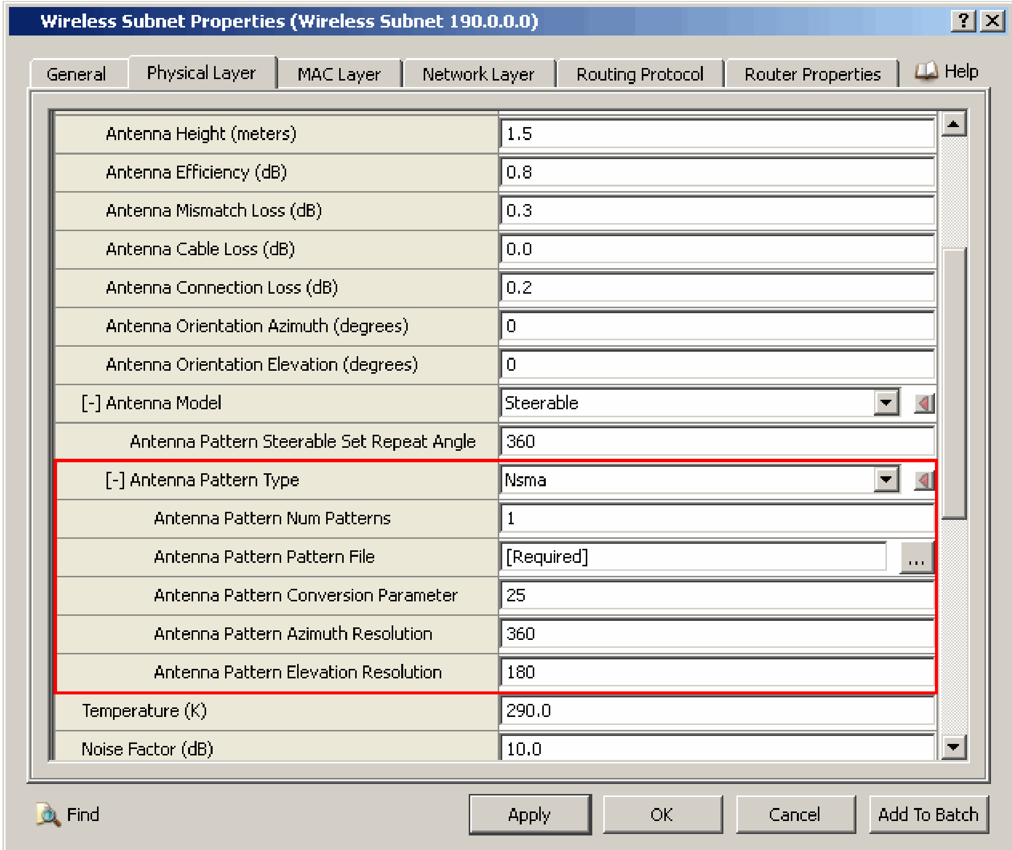

FIGURE 3-21. Setting NSMA Pattern Parameters

TABLE 3-35. Command Line Equivalent of NSMA Pattern Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Antenna Pattern Num Patterns	Subnet, Interface	`ANTENNA-PATTERN-NUM-PATTERNS`
Antenna Pattern Pattern File	Subnet, Interface	`ANTENNA-PATTERN-PATTERN-FILE`
Antenna Pattern Conversion Parameter	Subnet, Interface	`ANTENNA-PATTERN-CONVERSION-PARAMETER`
Antenna Pattern Azimuth Resolution	Subnet, Interface	`ANTENNA-PATTERN-AZIMUTH-RESOLUTION`
Antenna Pattern Elevation Resolution	Subnet, Interface	`ANTENNA-PATTERN-ELEVATION-RESOLUTION`

Setting Parameters

- Set **Antenna Pattern Pattern File** to the name of the pattern file, respectively. See Section 3.5.3.1.4 for the format of this file.

8. If **Antenna Model** is set to *Patterned* or *Switched Beam*, then set the dependent parameters in the same way as for the Steerable antenna model.

3.5.4.2 Configuring Custom Antenna Models

This section describes how to configure custom antenna models using the GUI. Custom antenna models are imported into the scenario by specifying an Antenna Models file or by using the Antenna Model Editor. Custom antenna models are created using the Antenna Model Editor.

Section 3.5.4.2.1 describes how to use the Antenna Model Editor to import, create, and modify antenna models.

Specifying Antenna Models File

To use custom antenna models in a scenario, the name of the file that contains the antenna models must be specified. To specify the name of the Antenna Models file, do the following (or import this file using the Antenna Model Editor, as described in Section 3.5.4.2.1):

1. Go to **Scenario Properties Editor > Supplemental Files**.
2. Set the parameter **Antenna Models File** to the name of the Antenna Models file. See Section 3.5.3.2.1 for the format of this file.

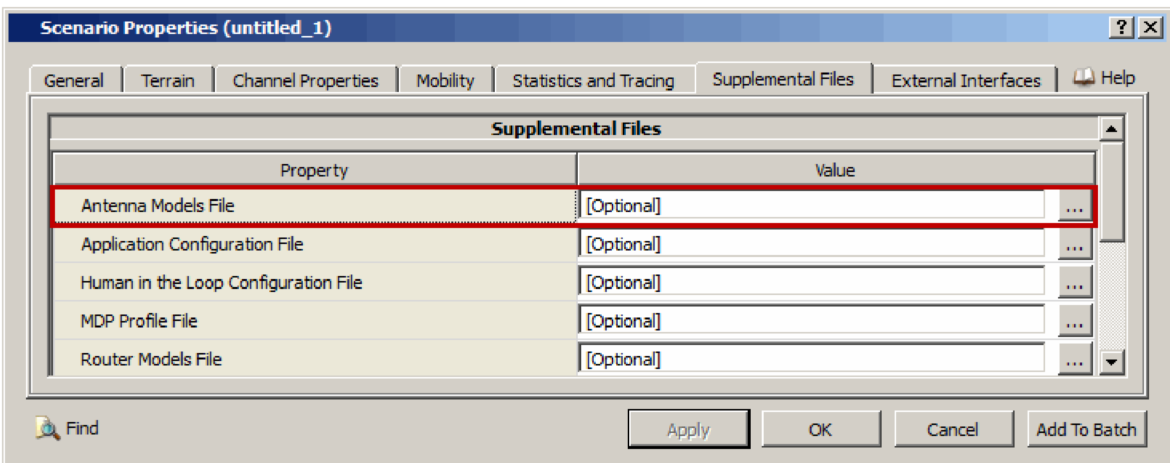

FIGURE 3-22. Specifying the Antenna Models File

TABLE 3-36. Command Line Equivalent of Antenna Models File Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Antenna Models File	Global	`ANTENNA-MODEL-CONFIG-FILE`

Configuring Custom Antenna Model for an Interface

To configure a custom antenna model for an interface, do the following:

1. Go to one of the following locations:
   - To set properties for a specific subnet, go to **Wireless Subnet Properties Editor > Physical Layer**.
   - To set properties for a specific interface of a node, go to one of the following locations:
     - **Interface Properties Editor > Interfaces > Interface # > Physical Layer.**
     - **Default Device Properties Editor > Interfaces > Interface # > Physical Layer**.

   In this section, we show how to configure the antenna model in the Wireless Subnet Properties Editor. Parameters can be set in the other properties editors in a similar way.
2. You can specify a custom antenna model if you have specified an Antenna Models File or imported or created custom antenna models using the Antenna Model Editor (see Section 3.5.4.2.1).

   To specify a custom antenna model, set **Specify Antenna Model From File** to *Yes* and select a value for the parameter **Antenna Model** from the list. The names of all imported or created antenna models appear in the list.

   For the following parameters, the values associated with the selected model in the Antenna Models File are used:
   - **Antenna Gain**
   - **Antenna Height**
   - **Antenna Efficiency**
   - **Antenna Mismatch Loss**
   - **Antenna Cable Loss**
   - **Antenna Connection Loss**

   You can modify any of these parameters. If you modify any of these parameters, the modified value will be used instead of the value in the Antenna Models File.

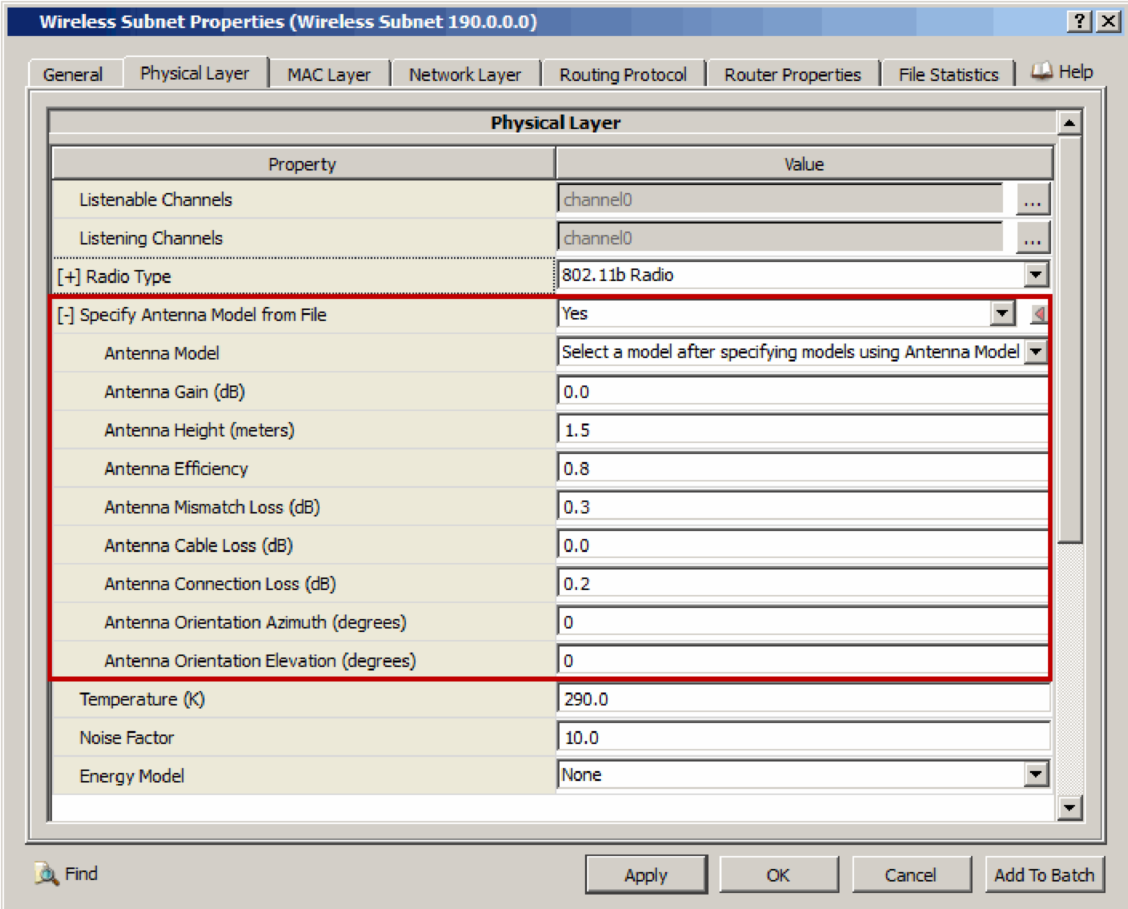

FIGURE 3-23. Specifying a Custom Antenna Model

TABLE 3-37. Command Line Equivalent of Custom Antenna Model Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Antenna Model	Subnet, Interface	ANTENNA-MODEL
Antenna Gain	Subnet, Interface	ANTENNA-GAIN
Antenna Height	Subnet, Interface	ANTENNA-HEIGHT
Antenna Efficiency	Subnet, Interface	ANTENNA-EFFICIENCY
Antenna Mismatch Loss	Subnet, Interface	ANTENNA-MISMATCH-LOSS
Antenna Cable Loss	Subnet, Interface	ANTENNA-CABLE-LOSS
Antenna Connection Loss	Subnet, Interface	ANTENNA-CONNECTION-LOSS
Antenna Orientation Azimuth	Subnet, Interface	ANTENNA-OREINTATION-AZIMUTH
Antenna Orientation Elevation	Subnet, Interface	ANTENNA-ORIENTATION-ELEVATION

3.5.4.2.1 Using the Antenna Model Editor

The Antenna Model Editor allows importing selected antenna models from existing files, creating new antenna models, and modifying existing antenna models in a scenario. To open the Antenna Model Editor, select **Tools > Antenna Model Editor**.

Importing Antenna Models

The **Import** tab is used to import antenna models from an external file. To import antenna models do the following:

1. Click on the [...] button next to the **Select Antenna Models from Files** edit box.
2. Use the file browser dialog to select the desired file. This file should typically have a name ending in ".antenna-models". The list box on the left will be populated with the names of antenna models found in the file specified.
3. To import a single antenna model, select it from the list box on the left and press the [>] button.
4. To import all available antenna models, press the [>>] button.
5. To cancel the import of one or all of the antenna models, use the [<] or [<<] button.

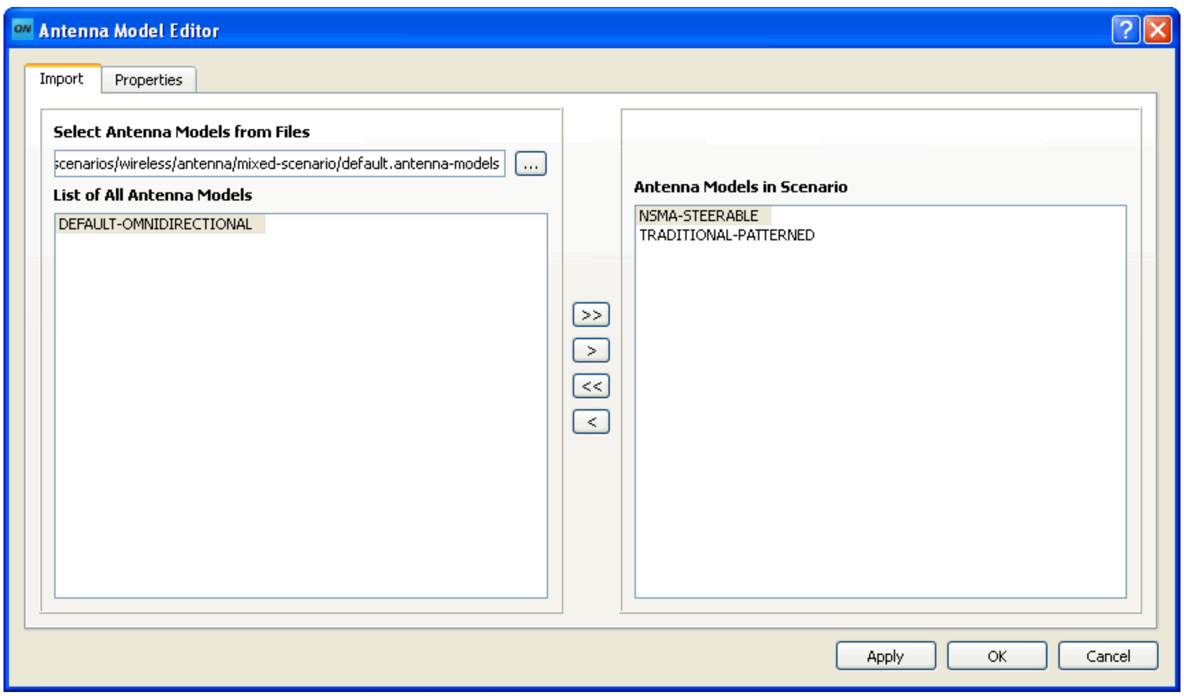

FIGURE 3-24. Importing Antenna Models

Adding, Removing and Modifying Antenna Models

The **Properties** tab is used to add, remove, or modify custom antenna models.

- To create a new antenna model, click on the  button. To change the automatically assigned name, select the new model from the list box on the left and then edit the name in the **Selected Model** text box. The desired properties can then be set using the embedded property editor on the right.
- To delete an antenna model, select it from the list box on the left and click on the  button.

- To change the properties of an existing antenna model, select it from the list box on the left and use the embedded property editor on the right.

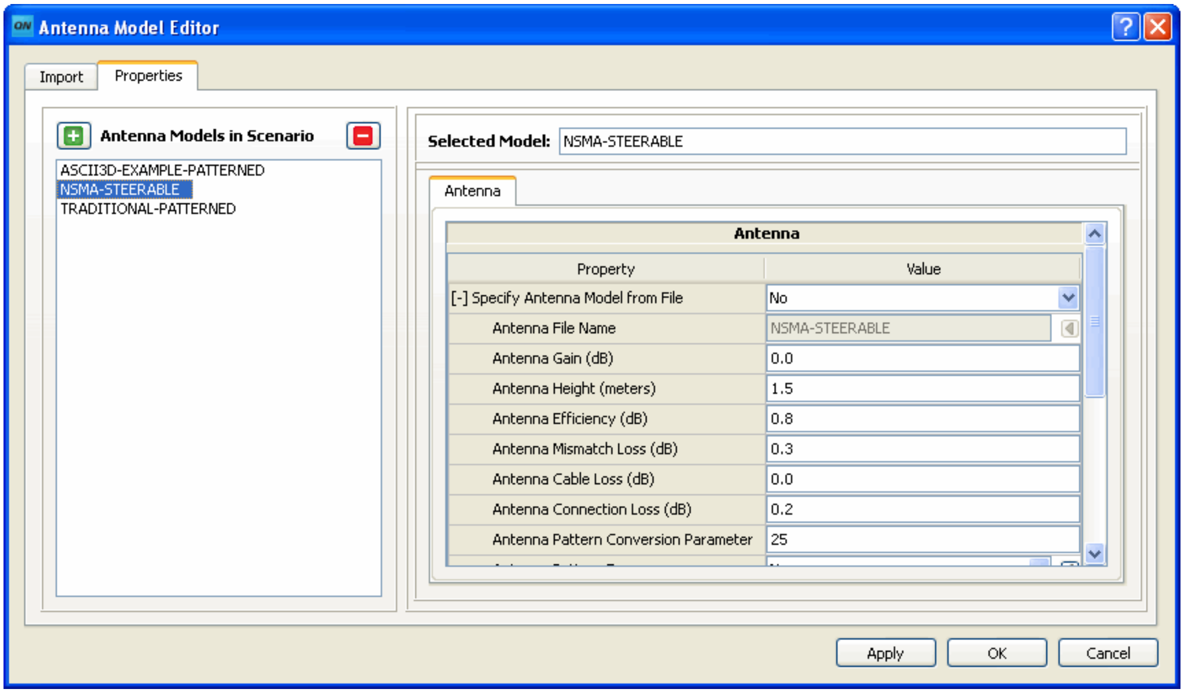

FIGURE 3-25. Modifying an Antenna Model

3.5.5 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the antenna models. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/antenna. Table 3-38 lists the sub-directory where each scenario is located.

TABLE 3-38. Antenna Model Scenarios Included in EXata

Scenario	Description
bkwd-comp	Shows the backward compatibility of antenna model.
bkwd-comp	Shows whether the antenna model has backward compatibility i.e. steerable, switched beam and omnidirectional antennas work fine if user tries to initialize them by mentioning them in the default.config file.
mixed-scenario	Shows whether the antenna model works well in a mixed scenario.
nonaligned-radiation-pattern	Shows that Patterned Antenna behaves properly in accordance with the 3D pattern file format (ASCII3D) with radiation pattern as nonaligned.
nsma-pattern	Shows that antenna model parses the NSMA pattern correctly and stores the gain values properly.

3.6 Bit Error Rate-based (BER) Reception Model

3.6.1 Description

The BER-based reception model determines the bit error rate for a Signal to Interference plus Noise Ratio (SINR) by looking up a pre-computed BER table. The BER tables can be obtained by experiments, link level simulations using MatLab, or other means. In general, the received packet quality is a function of the instant SINR value, packet length, and waveform of the signal.

The BER-based reception model can be used with only some of the PHY models. When the BER-based reception model is explicitly specified, the BER tables are contained in files specified by the user.

3.6.2 Command Line Configuration

To specify BER as the PHY reception model, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   PHY-RX-MODEL        BER-BASED
```

The scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

BER-based Reception Model Parameters

Table 3-39 lists the BER-based reception model parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 3-39. BER-based Reception Model Parameters

Parameter Name	Value	Description
`PHY-RX-BER-TABLE-FILE` *Required* *Scope:* All *Instances:* file number	Filename	Name of the file containing the bit error rate table. If multiple BER tables are specified, then `PHY-RX-BER-TABLE-FILE[0]` should correspond to the BER table for the lowest data rate used by the PHY model, `PHY-RX-BER-TABLE-FILE[1]` should correspond to the second lowest data rate, and so on. See Section 3.6.2.1 for the format of the BER Table file.

3.6.2.1 Format of the BER Table File

Each line in the BER Table file has the following format:

```
<SINR>   <BER>
```

where

`<SINR>`	Signal to noise and interference ratio.
`<BER>`	Bit error rate corresponding to the SINR value.

If the SINR value falls between two rows of the BER table, linear interpolation is used to calculate BER value corresponding to the SINT value.

EXata provides several pre-computed BER tables for different modulation and encoding schemes. Table 3-40 lists the BER table files provided with EXata. These tables are located in the folder EXATA_HOME/data/modulation.

TABLE 3-40. BER Table Files Included with EXata

File	Description
bpsk.ber	Binary phase-shift keying modulation. No encoding.
bpsk-turbo.ber	Binary phase-shift keying modulation with turbo encoding.
cck-5_5.ber.ber	Complimentary code keying for 5.5 Mbps.
cck-11.ber	Complimentary code keying for 11 Mbps.
dpsk.ber	Differential phase-shift keying modulation. No encoding.
dpsk-turbo.ber	Differential phase-shift keying modulation with turbo encoding.
dqpsk.ber	Differential quadrature phase-shift keying modulation. No encoding.
fsk2.ber	Binary Frequency-shift keying modulation. No encoding. May be used for analog data up to 16 kbits/s.
fsk8.ber	M-ary Frequency-shift keying modulation, M=8. No encoding. Provides support for ALE.
fsk8_golay.ber	M-ary Frequency-shift keying modulation, M=8 with Golay encoding. Provides support for ALE.
gmsk.ber	Gaussian minimum shift keying modulation. No encoding.
qam64.ber	64-Quadrature amplitude modulation. No encoding. May be used for the cases that have a 27Mbps capability over a 6MHz line.
qam64-convolutionalr12.ber	64-Quadrature amplitude modulation with convolutional encoding, and code rate 1/2. Provides the ability to use FEC.
qam64-convolutionalr23.ber	64-Quadrature amplitude modulation with convolutional encoding, and code rate 2/3. Provides the ability to use FEC.

3.6.3 GUI Configuration

To configure the BER-based reception model parameters, perform the following steps:

1. Go to one of the following locations:
   - To set properties for a specific subnet, go to **Wireless Subnet Properties Editor > Physical Layer**.
   - To set properties a specific interface of a node, go to one of the following locations:
     - **Interface Properties Editor > Interfaces > Interface # > Physical Layer**.
     - **Default Device Properties Editor > Interfaces > Interface # > Physical Layer**.

   In this section, we show how to configure BER-based reception model parameters for a specific subnet using the Wireless Subnet Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **Packet Reception Model** to *BER-based Reception Model* and set **Number of BER Tables** to the number of BER tables used.

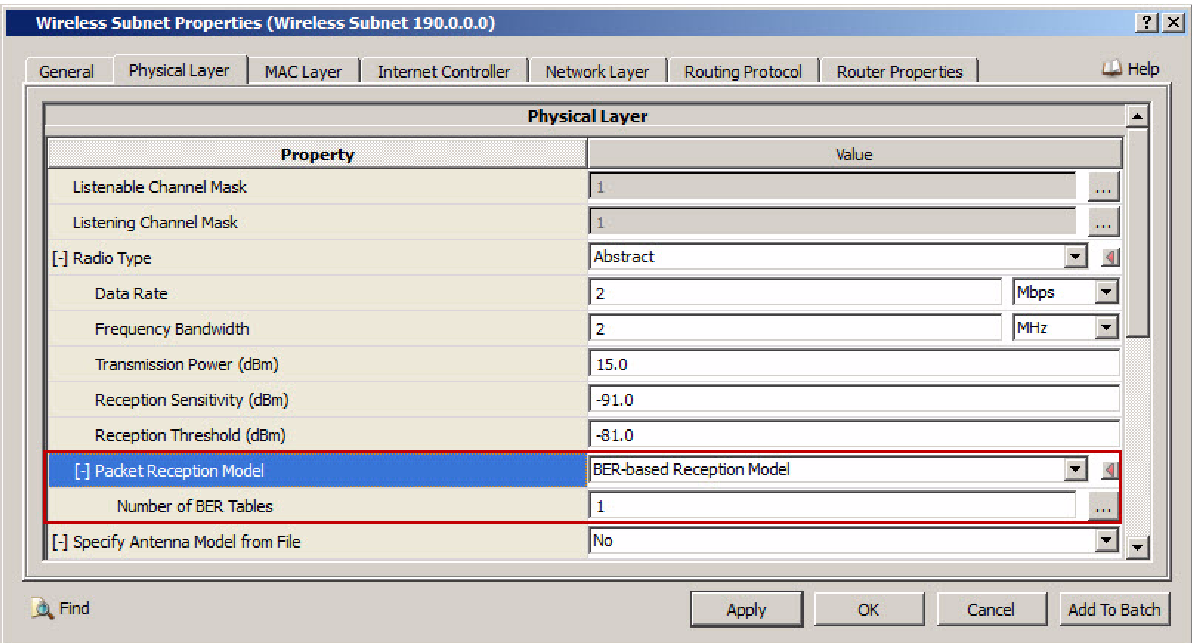

FIGURE 3-26. Setting BER-based Reception Model Parameters

Setting Parameters

- Set **Number of BER Tables** to a desired value as shown in Figure 3-26.

3. To configure the BER tables, do the following:

a. Click the **Open Array Editor** [...] button in the **Value** column for **Number of BER Tables**. This opens the Array Editor (Figure 3-27).

b. Set the parameters listed in Table 3-41 for each BER table index.

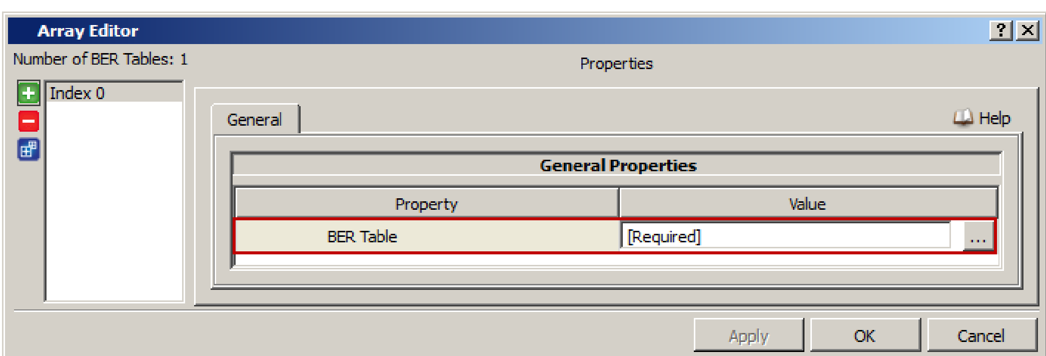

FIGURE 3-27. Setting BER Table Parameters

TABLE 3-41. Command Line Equivalent of BER Table Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
BER Table	Subnet, Interface	`PHY-RX-BER-TABLE-FILE`

Setting Parameters

- Set **BER Table [i]** to the name of the file containing the i th BER table. See Section 3.6.2.1 for the format of the BER Table file.
- If multiple BER tables are specified, then **BER Table[0]** should correspond to the BER table for the lowest data rate used by the PHY model, **BER Table[1]** should correspond to the second lowest data rate, and so on.

3.6.4 Statistics

No statistics are collected for the BER-based reception model.

3.7 Radio Energy Models

3.7.1 Description

The issue of energy saving is significant since in a battery-operated wireless node, the battery energy is finite and a node can only transmit a finite number of bits. The maximum number of bits that can be sent is defined by the total battery energy divided by the required energy per bit. Most of the pioneering research in the area of energy-constrained communication has focused on transmission schemes to minimize the transmission energy per bit.

3.7.1.1 Description of Radio Energy Models

In this part, we present a generic radio energy model which is derived to estimate the consumed energy for reception and transmission. In a wireless radio transceiver, energy is dissipated in active mode when the radio transmits or receives a packet, in sleep or idle modes of the transceivers, and for the transition among states. Figure 3-28 depicts the components of radio model which consume energy at the receiver and transmitter.

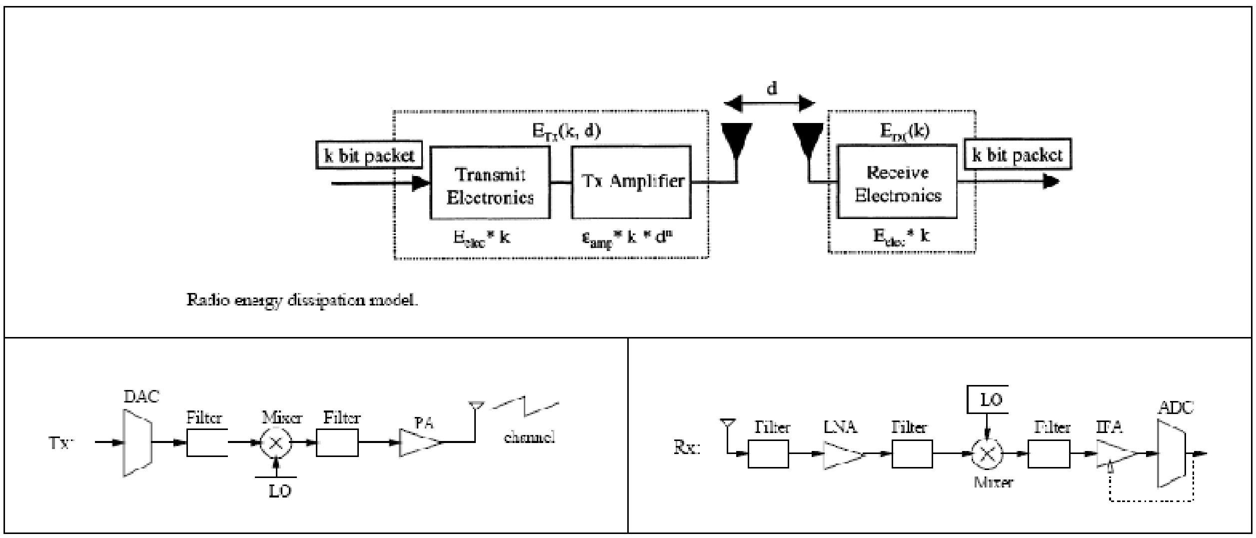

FIGURE 3-28. Radio Energy Dissipation Model

The total energy consumption *E* required to send *k* bits consists of three components:

$$\begin{aligned} E &= P_{on} \cdot T_{on} + P_{sp} \cdot T_{sp} + P_{tr} \cdot T_{tr} + P_{Idle} \cdot T_{Idle} \\ &= (P_t + P_{c0}) \cdot T_{on} + P_{sp} \cdot T_{sp} + P_{tr} \cdot T_{tr} + P_{Idle} \cdot T_{Idle} \end{aligned} \qquad (1)$$

where P_{on}, P_{sp} , P_{Idle} and P_{tr} are power consumption values for the active mode, the sleep mode, Idle mode and the transient mode, respectively. Similarly, *T* represent the time duration that the transceiver stays at each state. The active mode power P_{on} comprises the transmission signal power P_t and the circuit power consumption P_{co} in the whole signal path. Specifically, P_{co} consists of the mixer power consumption P_{mix}, the frequency synthesizer power consumption P_{syn}, the LNA power consumption P_{LNA}, the active filter power consumption P_{filt} at the transmitter, the active filter power consumption P_{filr} at the receiver, the IFA power consumption P_{IFA}, the DAC power consumption P_{DAC}, the ADC power consumption P_{ADC}, and the power amplifier power consumption P_{amp}, where:

$$P_{amp} = \alpha \cdot P_t \qquad (2)$$
$$\alpha = \frac{\beta}{\mu} - 1$$

with μ the drain efficiency of the RF power amplifier and β the Peak to Average Ratio (PAR), which is dependent on the modulation scheme and the associated constellation size. Note that the different classes of amplifiers have different values of μ. where $\mu = 0.35$, which is a practical value for class-A RF power amplifiers(e.g. linear amplifiers used for MQAM modulation scheme) the value of $\mu = 0.75$ corresponds to a class-B or a higher-class (C,D or E) power amplifier(e.g. non-linear amplifiers used for MFSK modulation scheme.)

The value of β is determined by the modulation scheme. For examples, in MQAM modulation β is as follows:

$$\beta = \frac{3 \cdot (\sqrt{M} - 1)}{\sqrt{M} + 1} \qquad (3)$$

By employing coding or MFSK modulation PAR can be reduced to almost $\beta = 1$.

Although strictly speaking P_t should be part of the total amplifier power consumption, here we define P_{amp} as the value excluding the transmission signal power for convenience.

The values of P_{on} at transmitters, P_{ont}, and receivers, P_{onr}, are given by:

$$P_{ont} = P_t + P_{amp} + P_{ct} = (1 + \alpha) \cdot P_t + P_{ct} \qquad (4)$$
$$P_{onr} = P_{cr}$$

Meanwhile, $P_{ct} = P_{mix} + P_{syn} + P_{filt} + P_{DAC}$ and $P_{cr} = P_{mix} + P_{syn} + P_{LNA} + P_{filr} + P_{IFA} + P_{ADC}$ denote the circuit power consumption (excluding the power amplifier power consumption) in the active mode at the transmitter and the receiver, respectively. One necessary modification in the hardware configuration system of digital modulation such as MFSK compared to the analog such as MQAM is that the mixer and the DAC at the transmitter should be deleted therefore for digital modulation $P_{ct} = P_{syn} + P_{filt}$

The start-up time for other circuit blocks is negligible compared to that of the frequency synthesizers. Hence, the optimal strategy for the start-up process is to turn on the frequency synthesizers first and once they settle down, to turn on the rest of the circuits. As a result, there is no energy wasted while the transceiver waits for the frequency synthesizers to settle down. Hence, P_{tr} merely needs to include the power consumption of the frequency synthesizers.

In the sleep mode, the power consumption is dominated by the leaking current of the switching transistors if the circuitry is properly designed.

3.7.1.2 EXata Radio Energy Models

This section describes the radio energy models implemented in EXata.

3.7.1.2.1 Radio-specific Energy Models

The model reads the energy consumption specifications of the radio where the specifications are defined by the configuration parameters which are the power supply voltage of the radio, electrical current load consumed in *Transmit*, *Receive*, *Idle*, and *Sleep* modes

From the radio interface data sheets provided by the vendors of the wireless interfaces, we have stored the specifications of several commonly used wireless interfaces such as given the name of vendor as configuration parameter, the energy model specifications are loaded for that wireless interface.

MicaZ Radio Energy Model

The MicaZ radio energy model is a radio-specific energy model which is pre-configured with the specification of power consumption of MicaZ motes (embedded sensor nodes).

Table 3-42 gives the specifications of the MicaZ radio energy model.

TABLE 3-42. Specifications of MicaZ Energy Model

Symbol	MCU Mode	Radio Mode	Power @ 3V
P_{TX}	Active	TX (0 dBm)	48.0 mW
	Active	TX (-1 dBm)	45.0 mW
	Active	TX (-3 dBm)	42.0 mW
	Active	TX (-5 dBm)	39.0 mW
	Active	TX (-7 dBm)	36.0 mW
	Active	TX (-10 dBm)	33.0 mW
	Active	TX (-15 dBm)	26.4 mW
PRX	Active	RX	56.5 mW
PCCA	Active	CCA	55.8 mW
P1	Active	Idle	10.79 mW
PMCU	Active	Sleep	1.50 mW
PS	Sleep	Sleep	30 uW

Mica Motes Radio Energy Model

The Mica Motes radio energy model is a radio-specific energy model which is pre-configured with the specification of power consumption of Mica motes (embedded sensor nodes).

Table 3-43 gives the specifications of the Mica Motes radio energy model.

TABLE 3-43. Specifications of Mica Motes Energy Model

Component	Current (mA)
Radio	
RX	9.60
TX (dBm)	
-20	5.30
-5	8.90
0	10.40
+5	14.8
+10	26.70

3.7.1.2.2 Generic Radio Energy Model

The generic model has been derived from the equations and the modules presented in the previous section.The main feature of the model is estimation of energy consumption for the radios with common modulation schemes (analog and digital) and common classes of amplifiers (class-A,B,C,D). Furthermore, the model can estimate energy consumption in transmitter for the case of continuous transmit power level.

The users don't need to know the detailed of the Generic Model as described in the previous section.

The parameters which are optionally required for generic model to be able to more accurately estimate the power or the amount of current loaded on battery are:

- **Amplifier drain efficiency,** μ (c.f. equation 2)**,** about 35% for class-A and about 75% for higher classes. The default value is 75%.
- **Peak to average power ratio** (PAR), β (c.f. equation 2)**,** about 1 for digital modulation and >1 for QAM. The default value is 1.
- **The power supply voltage**, V_{dd}. The default value is 3 V.
- **Idle power consumption**, P_{Idle}. If not configured, we consider reception power, P_{cr}, as the idle power consumption.
- **Sleep power consumption**, P_{sp}. The default value is 0 mW.

Those parameters are all well-know parameters in RF circuit design; if the user configures them generic energy model is fairly accurate and works well in case of continuous and variable transmission power; however, if user doesn't know about those parameters, the default values for those parameters are taken.

The generic model calculates the power for transmission and reception as of equation (4).

In this equation, P_t is transmission power which is given from PHY layer, α is the parameter which is calculated from the given configuration parameters (i.e., μ and β) as of equation (2). P_{ct} and P_{cr} are constant values which are listed in Table 3-44.

TABLE 3-44. Power Consumption in Circuitry of Radio Energy Dissipation Model

P_{mix} = 30.3 mW	P_{IFA} = 3mW
P_{INA} = 20.0 mW	$P_{filt} = P_{filr}$ = 2.5 mW
P_{syn} = 50 mW	P_{DAC} = 15.4 mW, P_{ADC} = 14mW

Note that $P_{ct} = P_{mix} + P_{syn} + P_{filt} + P_{DAC}$ and $P_{cr} = P_{mix} + P_{syn} + P_{LNA} + P_{filr} + P_{IFA} + \mathrm{P}_{ADC}$

As aforementioned, please also note that one necessary modification in the hardware configuration system of digital modulation such as MFSK compared to the analog such as MQAM is that the mixer and the DAC at the transmitter should be deleted therefore for digital modulation $P_{ct} = P_{syn} + P_{filt}$

By obtaining power from these equations and given the power supply voltage, V_{dd} (as a configuration parameter), the electrical current which should be loaded on the battery in transmission or reception of a packet can be calculated simply.

3.7.1.2.3 User-defined Radio Energy Model

The User-defined energy model is a configurable model that allows the user to specify the energy consumption parameters of the radio in different power modes. The configurable parameters include the power supply voltage of the radio's hardware, electrical current load consumed in *Transmit*, *Receive*, *Idle*, and *Sleep* modes.

3.7.2 Features and Assumptions

This section describes the implemented features, omitted features, assumptions and limitations of the Radio Energy model.

3.7.2.1 Implemented Features

- Fairly accurate estimates of energy consumed in transmission, reception, idle, and sleep modes.
- Account for energy consumed in circuitry (base-band and amplifier circuits) as well as energy consumed in power amplifier for emitting signals over the air.
- The Generic model takes into account variable and continuous transmission power.

3.7.2.2 Omitted Features

None.

3.7.2.3 Assumptions and Limitations

- Large amount of energy is consumed for transmission, reception, idle and sleep modes.
- Energy consumed in circuitry (base-band and amplifier circuits) and in power amplifier is taken into account for emitting signal over the air.
- The generic model takes into account the variable and continuous transmission power.
- Transmission power is constant during the simulation run.

3.7.3 Command Line Configuration

To specify the MicaZ radio energy model, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   ENERGY-MODEL-SPECIFICATION         MICAZ
```

To specify the Mica Motes radio energy model, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   ENERGY-MODEL-SPECIFICATION         MICA-MOTES
```

To specify the Generic radio energy model, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]  ENERGY-MODEL-SPECIFICATION        GENERIC
```

To specify the User-defined radio energy model, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]  ENERGY-MODEL-SPECIFICATION        USER-DEFINED
```

The scope of the parameter `ENERGY-MODEL-SPECIFICATION` can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

Note: The default value of the parameter `ENERGY-MODEL-SPECIFICATION` is `NONE`. If the radio energy model is not defined or if it is defined as `NONE`, no radio energy model is employed.

MicaZ Radio Energy Model Parameters

There are no additional configuration parameters for the MicaZ radio energy model.

Mica Mote Radio Energy Model Parameters

There are no additional configuration parameters for the Mica Motes radio energy model.

Generic Radio Energy Model Parameters

Table 3-45 describes the parameters to configure the Generic radio energy model. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 3-45. Generic Energy Model Configuration Parameters

Parameter	Value	Description
`ENERGY-POWER-AMPLIFIER-INEFFICIENCY-FACTOR` Optional *Scope:* All	Real *Default:* `6.5`	Amplifier inefficiency coefficient.
`ENERGY-TRANSMIT-CIRCUITRY-POWER-CONSUMPTION` Optional *Scope:* All	Real *Default:* `100.0` *Unit:* mW	Power consumed by circuitry of the transmitter.
`ENERGY-RECEIVE-CIRCUITRY-POWER-CONSUMPTION` Optional *Scope:* All	Real *Default:* `130.0` *Unit:* mW	Power consumed by the radio when the transceiver is in Idle state.

TABLE 3-45. Generic Energy Model Configuration Parameters (Continued)

Parameter	Value	Description
`ENERGY-SLEEP-CIRCUITRY-POWER-CONSUMPTION` Optional *Scope:* All	Real *Default:* `0.0` *Unit:* mW	Power consumed by the radio when the transceiver is in Sleep state.
`ENERGY-IDLE-CIRCUITRY-POWER-CONSUMPTION` Optional *Scope:* All	Real *Default:* `120.0` *Unit:* mW	Power consumed by the radio when the transceiver is in Idle state.
`ENERGY-SUPPLY-VOLTAGE` Optional *Scope:* All	Real *Default:* `6.5` *Unit:* volts	This parameter specifies the power supply voltage.
`ENERGY-MODEL-STATISTICS` Optional *Scope:* All	List: • `YES` • `NO` *Default:* `NO`	Indicates whether statistics are collected for Radio Energy Models.

User-Defined Radio Energy Model Parameters

Table 3-46 describes the parameters to configure the User-Defined radio energy model.

TABLE 3-46. User-Defined Energy Model Configuration Parameters

Parameter	Value	Description
`ENERGY-TX-CURRENT-LOAD` Optional *Scope:* All	Real *Default:* `280.0` *Unit:* mA	The amount of current consumed by the network interface when transmitting a signal
`ENERGY-RX-CURRENT-LOAD` Optional *Scope:* All	Real *Default:* `204.0` *Unit:* mA	The amount of current consumed by the network interface when receiving a signal.
`ENERGY-IDLE-CURRENT-LOAD` Optional *Scope:* All	Real *Default:* `174.0` *Unit:* mA	The amount of current consumed by the network interface when it's in IDLE mode.
`ENERGY-SLEEP-CURRENT-LOAD` Optional *Scope:* All	Real *Default:* `14.0` *Unit:* mA	The amount of current consumed by the network interface when it's in SLEEP mode.

TABLE 3-46. User-Defined Energy Model Configuration Parameters (Continued)

Parameter	Value	Description
`ENERGY-OPERATIONAL-VOLTAGE` Optional *Scope:* All	Real *Default:* `3.0` *Unit:* volts	This parameter specifies the power supply voltage required for the operation of the radio interface.
`ENERGY-MODEL-STATISTICS` Optional *Scope:* All	List: • `YES` • `NO` *Default:* `NO`	Indicates whether statistics are collected for Radio Energy Models.

3.7.4 GUI Configuration

In this subsection, we describe how to configure Radio Energy model parameters in the EXata GUI.

3.7.4.1 Configuring Radio Energy Model Parameters

To configure the Radio Energy Model parameters, perform the following steps:

1. Go to one of the following locations:
   - To set properties at the subnet level, go to **Wireless Subnet Properties Editor > Physical Layer**.
   - To set properties at the interface level, go to one of the following locations:
     - **Interface Properties Editor > Interfaces > Interface # > Physical Layer**.
     - **Default Device Properties Editor > Interfaces > Interface # > Physical Layer**.

   In this section, we show how to configure the general Radio Energy Model parameters in the Wireless Subnet Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **Energy Model** to the desired model as shown in Figure 3-29.

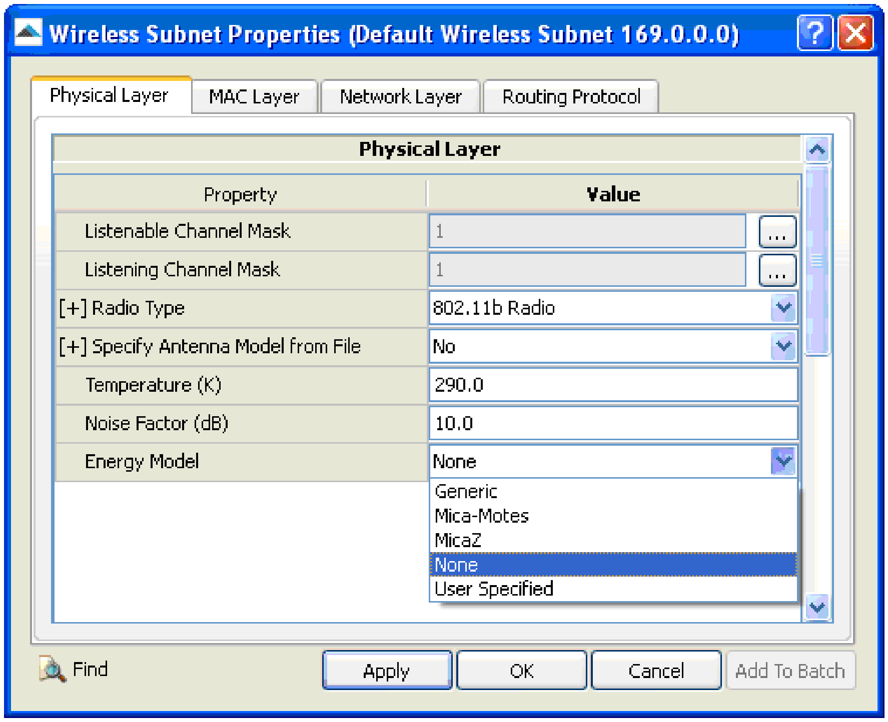

FIGURE 3-29. Setting Energy Model

TABLE 3-47. Command Line Equivalent of Energy Model Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Energy Model	Subnet, Interface	`ENERGY-MODEL-SPECIFICATION`

3. If **Energy Model** is set to be *Generic*, set the dependent parameters listed in Table 3-48.

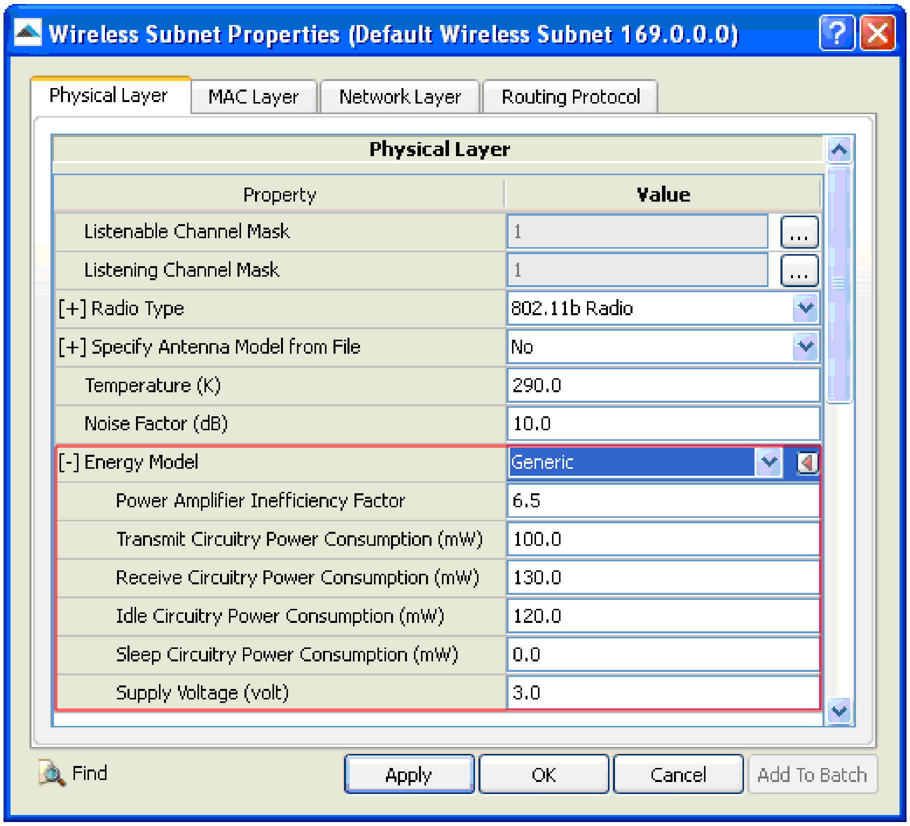

FIGURE 3-30. Setting Generic Model Parameters

TABLE 3-48. Command Line Equivalent of Generic Model Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Power Amplifier Inefficiency factor	Subnet, Interface	`ENERGY-POWER-AMPLIFIER-INEFFICIENCY-FACTOR`
Transmit Circuitry power Consumption	Subnet, Interface	`ENERGY-TRANSMIT-CIRCUITRY-POWER-CONSUMPTION`
Receive Circuitry power Consumption	Subnet, Interface	`ENERGY-RECEIVE-CIRCUITRY-POWER-CONSUMPTION`
Idle Circuitry power Consumption	Subnet, Interface	`ENERGY-IDLE-CIRCUITRY-POWER-CONSUMPTION`
Sleep Circuitry power Consumption	Subnet, Interface	`ENERGY-SLEEP-CIRCUITRY-POWER-CONSUMPTION`
Supply Voltage (volt)	Subnet, Interface	`ENERGY-SUPPLY-VOLTAGE`

4. If Energy Model is set to be *User Specified*, set the dependent parameters Listed in Table 3-49.

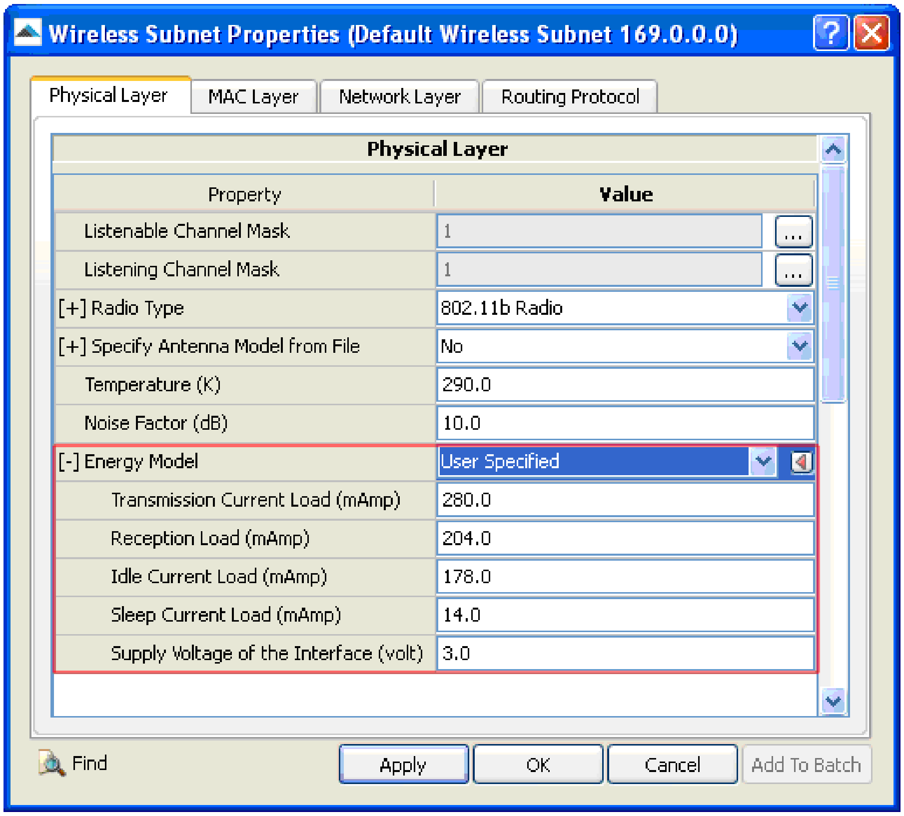

FIGURE 3-31. User Specified Model Parameters

TABLE 3-49. Command Line Equivalent of User Specified Model Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Transmit Current load	Subnet, Interface	`ENERGY-TX-CURRENT-LOAD`
Reception Load	Subnet, Interface	`ENERGY-RX-CURRENT-LOAD`
Idle Current Load	Subnet, Interface	`ENERGY-IDLE-CURRENT-LOAD`
Sleep Current Load	Subnet, Interface	`ENERGY-SLEEP-CURRENT-LOAD`
Supply Voltage of Interface	Subnet, Interface	`ENERGY-OPERATIONAL-VOLTAGE`

3.7.4.2 Configuring Statistics Parameters

Statistics for Radio Energy Model can be collected at the global and node levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for Radio Energy models and other Physical Layer Models, check the box labeled **PHY/Radio** in the appropriate properties editor.

TABLE 3-50. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
PHY/Radio	Global, Node	`PHY-LAYER-STATISTICS`

3.7.5 Statistics

This section describes the file and dynamic statistics of the Radio Energy model.

3.7.5.1 File Statistics

Table 3-51 shows the Radio Energy model statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 3-51. Radio Energy Model Statistics

Statistic	Description
Energy consumed (in mWhr) in Transmit mode	Total energy (power) consumed (in mWhr) by radio interface in Transmission mode
Energy consumed (in mWhr) in Receive mode	Total energy (power) consumed (in mWhr) by radio interface in reception mode
Energy consumed (in mWhr) in Idle mode	Total energy (power) consumed (in mWhr) by radio interface in idle mode
Energy consumed (in mWhr) in Sleep mode	Total energy (power) consumed (in mWhr) by radio interface in sleep state
Percentage of time in Sleep mode	Specifies the percentage of time that the interface has been in sleep mode.
Percentage of time in Transmit mode	Specifies the percentage of time that the interface has been in transmit mode.
Percentage of time in Receive mode	Specifies the percentage of time that the interface has been in Receive mode.
Percentage of time in Idle mode	Specifies the percentage of time that the interface has been in Idle mode.

3.7.5.2 Dynamic Statistics

The following dynamic statistics are enabled for the Radio Energy model (refer to Chapter 6 of *EXata User's Guide* for details of viewing dynamic statistics in the GUI during the simulation):

- Electrical Load (mA)

3.7.6 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the Radio Energy models. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/energy-models. Table 3-52 lists the sub-directory where each scenario is located.

TABLE 3-52. Radio Energy Model Scenarios Included in EXata

Scenario Sub-directory	Description
user-defined-ifx	Shows USER-DEFINED energy model for the radio interface.
mica-motes-ifx	Shows mica-motes energy model for the radio interface. All the nodes in this scenario are battery-operated devices and are configured by simple linear battery model. The radio interfaces for all nodes are configured with Mica (CC1100 sensor radio chip) therefore energy is consumed by those interfaces according to the energy specification of CC1100(included in the Energy Model reference lib document)
micaz-ifx	Shows micaZ energy model for the radio interface. All the nodes in this scenario are battery-operated devices and are configured by simple linear battery model. The radio interfaces for all nodes are configured with MicaZ therefore energy is consumed by those interfaces according to the energy specification of micaZ (included in the Energy Model reference lib document)

3.7.7 References

1. S. Cui, A. Goldsmith and A. Bahai, "Energy-constrained Modulation Optimization", IEEE Transactions on Wireless Communications, Vol. 4, Sept. 2005, 2349-2360.
2. Laura Marie Feeney and Martin Nilsson, "Investigating the energy consumption of a wireless network interface in an ad hoc networking environment", IEEE Conference on Computer Communications (INFOCOM), Vol. 3, April 2001, 1548-1557.

3.8 SNR-based Reception Model

3.8.1 Description

The Signal-to-Noise Ratio (SNR)-based model uses a user-specified threshold to evaluate reception quality. If the Signal to Interference plus Noise Ratio (SINR) value of the received signal is larger than this threshold, the packet is successfully received; otherwise, the packet is treated as corrupted.

3.8.2 Command Line Configuration

To specify SNR as the PHY reception model, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   PHY-RX-MODEL        SNR-BASED
```

The scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

SNR-based Reception Model Parameters

Table 3-53 lists the SNR-based reception model parameters specified in the scenario configuration (.config) file. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 3-53. SNR-based Reception Model Parameters

Parameter Name	Value	Description
`PHY-RX-SNR-THRESHOLD` *Required* *Scope:* All	Real *Unit:* `dB`	Specifies the threshold value for likely error-free reception.

3.8.3 GUI Configuration

This section describes how to configure SNR-based Reception model in the GUI.

Configuring SNR-based Reception model Parameters

To configure the SNR -based Reception parameters, perform the following steps:

1. Go to one of the following locations:
   - To set wireless subnet properties, go to wireless subnet **Properties Editor > Physical Layer > Radio Type** *[Abstract]* **> Packet Reception Model**.
   - To set properties for a specific interface of a node, go to **Node Interfaces Properties Editor > Interface # > Physical Layer > Radio Type** *[Abstract]* **> Packet Reception Model**.
2. Set **Packet Reception Model** to *SNR-based Reception Model* and set the dependent parameters of the model, as listed in Table 3-54.

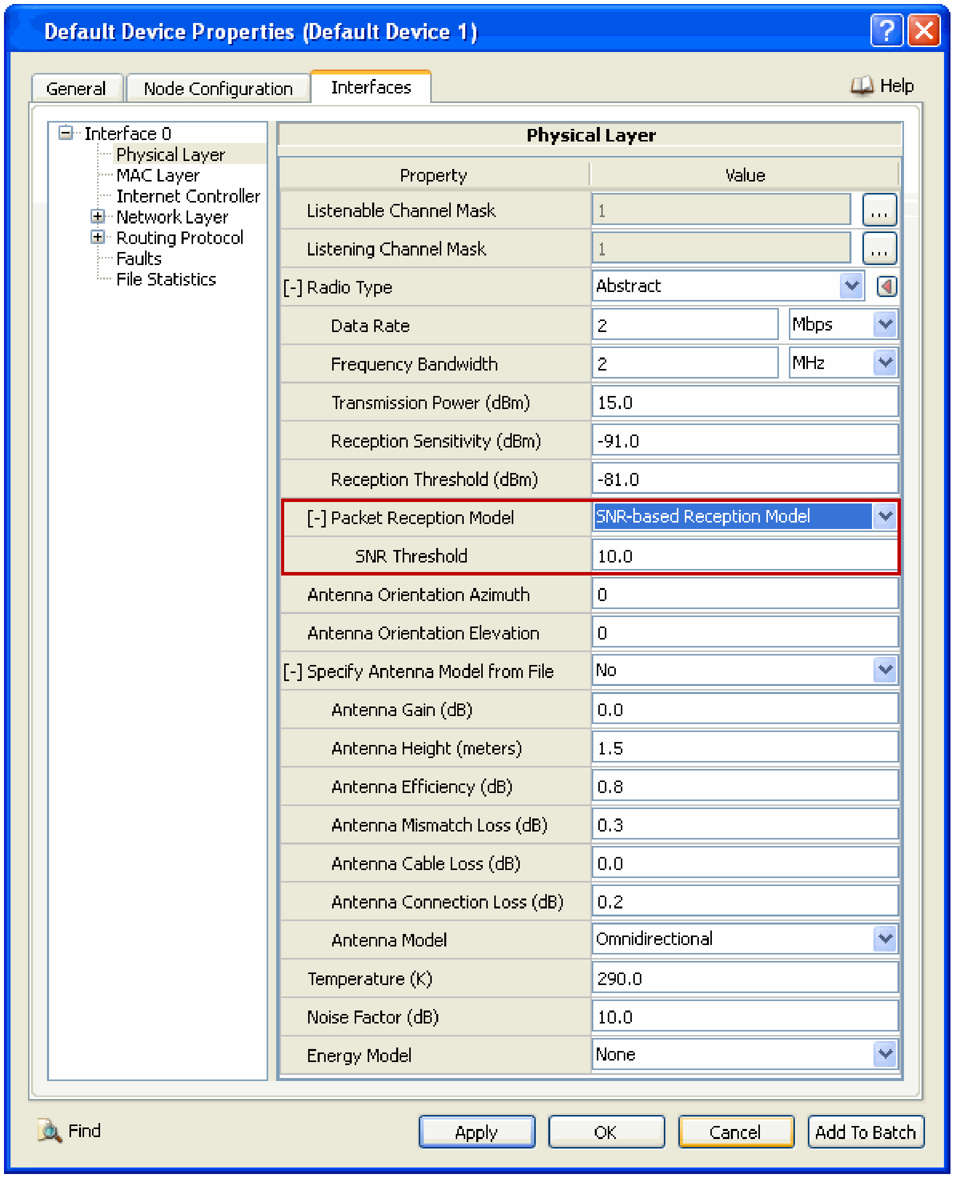

FIGURE 3-32. Setting SNR-based Reception Parameters

TABLE 3-54. Command Line Equivalent of SNR-based Reception Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
SNR Threshold	Node, Subnet, Interface	`PHY-RX-SNR-THRESHOLD`

4 MAC Layer Models

This chapter describes features, configuration requirements and parameters, statistics, and scenarios for MAC Layer Models, and consists of the following sections:

- 802.11 MAC Protocol
- 802.11e MAC Protocol
- 802.11n MAC Protocol
- 802.11s MAC Protocol
- Abstract Network Equation - Satellite (ANESAT) Model
- Aloha MAC Protocol
- Carrier Sense Multiple Access (CSMA) MAC Protocol
- Generic MAC Protocol
- Microwave Links
- Multiple Access Collision Avoidance (MACA) MAC Protocol
- Time Division Multiple Access (TDMA) MAC Protocol

4.1 802.11 MAC Protocol

The EXata 802.11 MAC model is based on the IEEE Standard 802.11 - 1999 standard.

The IEEE 802.11 standard defines a set of MAC and PHY specifications for wireless LAN, also known as WiFi. It was developed by the IEEE 802.11 working group. The original standard was developed in 1997. Later, several amendments have been proposed to extend 802.11 at both the MAC and physical layers to support various features such as higher bandwidth, QoS, security, and so on.

4.1.1 Description

IEEE 802.11 defines two different architectures, BSS (Basic Service Set) and IBSS (Independent Basic Service Set). In BSS (also known as Infrastructure mode), wireless stations (STAs) are associated with an Access Point (AP). All communications take place through the AP. In IBSS (also known as Ad Hoc mode) stations can communicate directly to each other provided, they are within each other's transmission range.

IEEE 802.11 MAC defines two access mechanisms:

- **Distributed Coordination Function (DCF)**: DCF provides distributed channel access based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). This mechanism is mandatory.
- **Point Coordination Function (PCF)**: PCF provides centrally controlled channel access through polling. This mechanism is optional.

IEEE 802.11 standard also defines the Power Saving (PS) Mode for reducing the energy consumption at stations.

4.1.1.1 DCF Procedure

The fundamental access method of the IEEE 802.11 MAC is DCF. The DCF shall be implemented in all STAs, for use within both ad hoc and infrastructure network configurations. For a STA to transmit, it shall sense the medium to determine, if another STA is transmitting. If the medium is not determined to be busy, then the transmission may proceed. If the medium is determined to be busy, the STA shall defer until the end of the current transmission.

The CSMA/CA distributed algorithm mandates that a gap of a minimum specified duration exist between contiguous frame sequences. A transmitting STA shall ensure that the medium is idle for this required duration before attempting to transmit again.

After deferral to an ongoing transmission, or prior to attempting to transmit again immediately after a successful transmission, the STA shall select a random backoff interval and shall decrement the backoff interval counter while the medium is idle. A refinement of the method may be used under various circumstances to further minimize collisions. Here, the transmitting and receiving STA exchange short control frames (Request-To-Send (RTS) and Clear-To-Send (CTS) frames) after determining that the medium is idle and after any deferrals or backoffs, prior to data transmission.

4.1.1.2 PCF Procedure

In the PCF procedure, the access to the channel is centralized by using a poll-based protocol controlled by the Point Coordinator. The access points generally serve as PCs. The PCF mode provides contention free service to the stations.

In PCF mode, a frame is divided into two parts: contention-free period (CFP) and contention period (CP). The PC indicates the start of the contention free period by sending a beacon frame which contains the PCF related information (for example, the CFP parameter set). The CFP is repeated after a fixed interval that is contention-free repetition interval.

After sending the beacon, the PC starts polling stations one by one in the order of their association IDs. If the PC has a data packet to send to the station, it sends the polling packet piggy-backed on the data packet. If the PC does not have any data to send, it sends only a polling packet.

If a polled station has any data to send to PC, it piggy-backs the data on the ACK packet. If the polled station does not have any data to send, it sends a NULL packet in response to the poll by the PC.

4.1.1.3 Power Saving Mode

Power saving mode is used to reduce the energy consumption at the station nodes. Three distinct building blocks are provided to support power savings: a Wakeup Procedure, a Sleep Procedure, and a Power Save Poll (PS-Poll) Procedure. A station can combine these power management building blocks in various manners for different applications.

Wakeup Procedure

There are two reasons for the STA to wake up: to transmit pending data or to receive buffered data from an access point. Waking up to transmit data is a straightforward operation, driven by the STA. The decision to wake up and receive data is also made by the STA after monitoring its pending data bit in a periodic beacon frame sent out by its AP. Once the STA decides to transition from sleep mode to active mode, it notifies the AP by sending a frame with the power-save (PS) bit set to active. Following such transmission, the STA remains active so the AP can send any buffered downlink frames.

Sleep Procedure

Similar to the wakeup procedure, a STA in the active mode needs to complete a successful STA-initiated frame exchange sequence with the PS bit set to sleep in order to transition into the sleep mode. Following this operation, the AP buffers all the downlink frames to this STA.

PS-Poll Procedure

Instead of waiting for the AP to transmit the buffered downlink frames, a STA in sleep mode can solicit an immediate delivery from its AP by using a PS-Poll frame. Upon receiving this PS-Poll, the AP can immediately send one buffered downlink frame (immediate data response) or simply send an acknowledgement message and respond with a buffered data frame later (delayed data response). For the immediate data response case, the STA can stay in the sleep state after finishing this frame exchange because the AP can only send a buffered downlink frame in response to the PS-poll from the STA. For the delayed data response case, the STA has to transition to the active state until it receives a downlink frame from the AP.

4.1.2 Features and Assumptions

This section describes the implemented features, omitted features, assumptions and limitations of the 802.11 MAC model.

4.1.2.1 Implemented Features

DCF Mode

- Active and passive scanning.
- Dynamic association.
- Authentication procedure.
- Association procedure.
- De-authentication procedure.
- DCF procedure.
- Power save mode
  - Management frames such as TIM/ATIM, DTIM, PS-Poll etc.

- Awake and Doze states at a STA.
- Infrastructure mode support the packet buffering, delivery and aging functionality in power saving mode for STAs at AP. In this mode AP can buffer the unicast, broadcast and multicast packets.
- Ad hoc mode (IBSS) supports the packet buffering, delivery and aging functionality in power saving mode for STAs.
- Support mixed scenario in Infrastructure Mode where some STAs are power saving enabled while some are not.

PCF Mode

- PCF is working in three Modes as POLL & DELIVER, DELIVER ONLY and POLL ONLY.
- Poll save by count procedure.
- Operation with overlapping point-coordinated BSSs.

4.1.2.2 Omitted Features

DCF Mode

- Fragmentation.
- Relay of data packets at AP.
- Beacon in IBSS mode(non PS mode).
- Association in IBSS mode.

PCF Mode

- Use of more data bit in data frames to indicate pending data at stations.

PS Mode

- Power Saving mode under PCF.
- Power saving mode for 802.11e.

4.1.2.3 Assumptions and Limitations

802.11 Model

- The routing of packets is assumed to be network layer based. (Sec 5.3: IEEE 802.11 does not constrain the DS to be either data link or network layer based.). A user configuration may allow or prevent an AP or PC from relaying packets outside the BSS.

Infrastructure/AP Mode

- In Sleep mode, if STA receive packet from network layer, it immediately changes the state from doze to active state.

Ad hoc/IBSS Mode

- All the nodes are in single IBSS to support ad hoc mode.
- Scan and join is not required for a node at the time of joining, for default IBSS.
- For ad hoc mode, Beacon interval and ATIM window, interval needs to be configured at subnet level.
- For an IBSS, PS Mode should be either enabled or disabled for all nodes.
- If node moved in another subnet, who’s working on the same channel frequency then subnet level configured parameter should be same for both subnets.

4.1.3 Command Line Configuration

To specify 802.11 MAC as the MAC protocol, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   MAC-PROTOCOL         MACDOT11
```

The scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

> **Note:** The DCF procedure is always enabled for the 802.11 MAC protocol. The default configuration is for ad hoc mode without power saving. The PCF procedure and power saving mode have to be explicitly enabled by setting parameters in the scenario configuration file.

Section 4.1.3.1 describes the general parameters to configure 802.11 MAC. Section 4.1.3.2 describes the parameters for the ad hoc mode (including power saving mode parameters). Section 4.1.3.3 describes the parameters for the infrastructure mode (including power saving mode and PCF procedure parameters).

See Section 1.2.1.3 for a description of the format used for the parameter tables.

4.1.3.1 General Configuration

Table 4-1 shows the general 802.11 MAC configuration parameters. This table includes parameters for the DCF procedure.

TABLE 4-1. 802.11 MAC General Parameters

Parameter	Value	Description
`MAC-DOT11-SHORT-PACKET-TRANSMIT-LIMIT` *Optional* *Scope:* All	Integer *Range:* > 0 *Default:* 7	Specifies the maximum number of times a short packet (CTS/ACK) will be re-transmitted if no response is received during previous attempts.
`MAC-DOT11-LONG-PACKET-TRANSMIT-LIMIT` Optional *Scope:* All	Integer *Range:* > 0 *Default:* 4	Specifies the maximum number of times a long packet (data) will be re-transmitted if no acknowledgement is received during previous attempts.
`MAC-DOT11-RTS-THRESHOLD` *Optional* *Scope:* All	Integer *Range:* ≥ 0 *Default:* 0 *Unit:* bytes	Specifies whether RTS/CTS is used based on data packet size. If data packet size is greater than `MAC-DOT11-RTS-THRESHOLD`, then RTS/CTS is used. Zero means always used RTS/CTS. Broadcast packets never use RTS/CTS.
`MAC-DOT11-STOP-RECEIVING-AFTER-HEADER-MODE` *Optional* *Scope:* All	List • `YES` • `NO` *Default:* `NO`	Specifies whether the node should stop receiving the packet after receiving the header if the packet is not addressed to the node.

TABLE 4-1. 802.11 MAC General Parameters (Continued)

Parameter	Value	Description
`MAC-DOT11-ASSOCIATION` *Optional* *Scope:* All	List • `NONE` • `DYNAMIC` *Default:* `NONE`	Specifies the association type. `NONE` : No association, which means the station is in as hoc mode. Set the ad hoc mode parameters described in Section 4.1.3.2. `DYNAMIC`: Dynamic association, which means the station is in infrastructure mode. Set the infrastructure mode parameters described in Section 4.1.3.3.
`MAC-DOT11-DIRECTIONAL-ANTENNA-MODE` *Optional* *Scope:* All	List • `YES` • `NO` *Default:* `NO`	Specifies whether the radio will use a directional antenna for transmission and reception. `YES` : The radio will use a directional antenna. The following directional antenna mode parameters are also applicable: • `MAC-DOT11-DIRECTION-CACHE-EXPIRATION-TIME` • `MAC-DOT11-DIRECTIONAL-NAV-AOA-DELTA-ANGLE` • `MAC-DOT11-DIRECTIONAL-SHORT-PACKET-TRANSMIT-LIMIT` `NO` : The radio will not use a directional antenna.
`MAC-DOT11-DIRECTION-CACHE-EXPIRATION-TIME` *Optional* *Scope:* All	Time *Range:* ≥ `0S`	Specifies the time period for which the radio keeps track of the last known direction of the receiver (for the directional antenna mode). **Note:** This parameter must be specified if `MAC-DOT11-DIRECTIONAL-ANTENNA-MODE` is set to `YES`.
`MAC-DOT11-DIRECTIONAL-NAV-AOA-DELTA-ANGLE` *Optional* *Scope:* All	Real *Unit:* degrees	Indicates the space that is NAV'ed when the radio overhears frames sent to neighboring nodes. **Note:** This parameter must be specified if `MAC-DOT11-DIRECTIONAL-ANTENNA-MODE` is set to `YES`.
`MAC-DOT11-DIRECTIONAL-SHORT-PACKET-TRANSMIT-LIMIT` *Optional* *Scope:* All	Integer *Range:* > `0` *Default:* `8`	Specifies the number of times the radio re-tries to transmit control frames directionally before transmitting it using omni-directional antenna mode. **Note:** This parameter is applicable only if `MAC-DOT11-DIRECTIONAL-ANTENNA-MODE` is set to *`YES`*. **Note:** The default value is calculated using relation `MAC-DOT11-DIRECTIONAL-SHORT-PACKET-TRANSMIT-LIMIT` = `MAC-DOT11-SHORT-PACKET-TRANSMIT-LIMIT` + 1.

TABLE 4-1. 802.11 MAC General Parameters (Continued)

Parameter	Value	Description
MAC-LAYER-STATISTICS *Optional* *Scope:* All	List: • YES • NO *Default:* NO	Indicates whether statistics are collected for MAC protocols, including 802.11 MAC.

4.1.3.2 Ad Hoc Mode Configuration

Table 4-2 shows additional parameters for the ad hoc mode.

TABLE 4-2. 802.11 MAC Ad-Hoc Mode Parameters

Parameter	Value	Description
MAC-DOT11-IBSS-SUPPORT-PS-MODE *Optional* *Scope:* All	List • YES • NO *Default:* NO	Specifies whether the IBSS supports PS mode. YES : IBSS supports PS mode. The following PS mode parameters are also applicable: • MAC-DOT11-IBSS-BEACON-START-TIME • MAC-DOT11-IBSS-BEACON-INTERVAL • MAC-DOT11-IBSS-PS-MODE-ATIM-DURATION NO : IBSS does not support PS mode. **Note:** All nodes in an IBSS should have this parameter set to the same value.
MAC-DOT11-IBSS-BEACON-START-TIME *Optional* *Scope:* All	Integer *Range: (see note)* *Default:* 1 *Unit:* TU	Specifies the beacon start time for the subnet. **Note:** This parameter is applicable only if MAC-DOT11-IBSS-SUPPORT-PS-MODE is set to *YES*. **Note:** The value of this parameter should be between 0S and MAC-DOT11-IBSS-BEACON-INTERVAL (both inclusive). **Note:** All nodes in an IBSS should have this parameter set to the same value.
MAC-DOT11-IBSS-BEACON-INTERVAL *Optional* *Scope:* All	Integer *Range:* *[0, 32767]* *Default:* 200 *Unit:* TU	Specifies the beacon interval in ad hoc mode. **Note:** This parameter is applicable only if MAC-DOT11-IBSS-SUPPORT-PS-MODE is set to *YES*. **Note:** All nodes in an IBSS should have this parameter set to the same value.

TABLE 4-2. 802.11 MAC Ad-Hoc Mode Parameters (Continued)

Parameter	Value	Description
MAC-DOT11-IBSS-PS-MODE-ATIM-DURATION *Optional* *Scope:* All	Integer *Range:* > 0 *Default:* 20 *Unit:* TU	Specifies the ATIM window duration in ad hoc mode. The ATIM window is a specific period of time during which only beacon or ATIM frames are transmitted. The ATIM duration should be less than the beacon interval. **Note:** This parameter is applicable only if MAC-DOT11-IBSS-SUPPORT-PS-MODE is set to *YES*. **Note:** All nodes in an IBSS should have this parameter set to the same value.

Note: A Time Unit (TU) is equal to 1024 micro-seconds.

4.1.3.3 Infrastructure Mode Configuration

Table 4-3 shows additional parameters to configure the infrastructure mode. Table 4-4 shows infrastructure mode parameters for an access point. Table 4-5 shows PCF procedure parameters for a point coordinator. Table 4-6 shows infrastructure mode parameters for a station.

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TABLE 4-3. 802.11 MAC Infrastructure Mode Parameters

Parameter	Value	Description
MAC-DOT11-SSID *Optional* *Scope:* All	String *Default:* TEST1	Specifies the SSID of the station or access point. **Note:** For a station to associate with an access point, both the station and the access point should have this parameter set to the same value.
MAC-DOT11-AP *Optional* *Scope:* All	List • YES • NO *Default:* NO	Specifies whether the node is an access point (AP) or a station (STA). YES : The node is an AP. Set the AP parameters listed in Table 4-4. NO : The node is an STA. Set the STA parameters listed in Table 4-6.

Table 4-4 shows infrastructure mode parameters for an access point.

TABLE 4-4. 802.11 MAC Infrastructure Mode Parameters for an Access Point

Parameter	Value	Description
MAC-DOT11-BEACON-START-TIME *Optional* *Scope:* All	Integer *Range: (see note)* *Unit:* TU	Specifies the beacon start time. If this parameter is not specified, the beacon start time is chosen randomly. **Note:** The value of this parameter should be between 0 and MAC-DOT11-BEACON-INTERVAL (both inclusive).

TABLE 4-4. 802.11 MAC Infrastructure Mode Parameters for an Access Point (Continued)

Parameter	Value	Description
MAC-DOT11-BEACON-INTERVAL *Optional* *Scope:* All	Integer *Range:* [0, 32767] *Default:* 200 *Unit:* TU	Specifies the beacon interval.
MAC-DOT11-DTIM-PERIOD *Optional* *Scope:* All	Integer *Range:* [0, 255] *Default:* 3 *Unit:* beacon interval	Specifies the DTIM frame interval. The DTIM period is the number of beacon intervals between DTIM frames. After transmission of a beacon containing a DTIM, the AP transmits all broadcast and multicast data.
MAC-DOT11-RELAY-FRAMES *Optional* *Scope:* All	List • YES • NO *Default:* YES	Specifies whether the AP relays frames to wireless nodes outside the BSS.
MAC-DOT11-AP-SUPPORT-PS-MODE *Optional* *Scope:* All	List • YES • NO *Default:* NO	Specifies whether the AP supports PS mode. YES : The AP supports PS mode. In this mode, the AP transmits TIM /DTIM information along with the beacon and buffers packets for STAs which are in sleep mode. NO : The AP does not support PS mode.
MAC-DOT11-STA-CHANNEL *Optional* *Scope:* All	Integer or string *Range:* ≥ 0 (if channel index is used)	Specifies the index or name of the channel that the AP uses as the operating channel.
MAC-DOT11-PC *Optional* *Scope:* All	List • YES • NO *Default:* NO	Specifies whether the node is the Point Coordinator (PC). YES : Node is a PC. Set the PCF procedure parameters listed in Table 4-5. NO : Node is not a PC.

Note: A Time Unit (TU) is equal to 1024 micro-seconds.

Table 4-5 shows PCF procedure parameters for a point coordinator.

TABLE 4-5. PCF Procedure Parameters for a Point Coordinator

Parameter	Value	Description
MAC-DOT11-PC-CF-REPETION-INTERVAL *Optional* *Scope:* All	Integer *Range:* [0, 10] *Default:* 1 *Unit:* DTIM period	Specifies the CFP repetitions interval in terms of the number of DTIM intervals.
MAC-DOT11-PC-CF-DURATION *Optional* *Scope:* All	Integer *Range:* > 0 *Default:* 50 *Unit:* TU	Specifies the Contention Free Duration in TU (Time Units). The value of this parameter should be between 0 and MAC-DOT11-PC-CF-REPETION-INTERVAL in Time Units.
MAC-DOT11-PC-DELIVERY-MODE *Optional* *Scope:* All	List • DELIVER-ONLY • POLL-AND-DELIVER • POLL-ONLY *Default:* POLL-AND-DELIVER	Specifies the mode of operation for the PC. DELIVERY-ONLY : A PC delivers only queued data and does not poll. POLL-AND-DELIVER: A PC polls as well as sends queued data. POLL-ONLY : Data packets are piggybacked on the polls.
MAC-DOT11-PC-POLL-SAVE *Optional* *Scope:* All	List • NONE • BY-COUNT *Default:* BY-COUNT	Specifies the poll save mode for the PC. NONE : Poll Save feature is disabled. BY-COUNT: Poll Save feature will be activated based on the count of null responses received by a PC when it polls the stations. Following additional parameters needs to set in this case: • MAC-DOT11-PC-POLL-SAVE-MIN • MAC-DOT11-PC-POLL-SAVE-MAX
MAC-DOT11-PC-POLL-SAVE-MIN *Optional* *Scope:* All	Integer *Range:* ≥ 0 *Default:* 1	Specifies the minimum threshold for poll save value. **Note:** This parameter is applicable only if MAC-DOT11-PC-POLL-SAVE is set to BY-COUNT.
MAC-DOT11-PC-POLL-SAVE-MAX *Optional* *Scope:* All	Integer *Range:* ≥ 0 *Default:* 10	Specifies the maximum threshold for poll save value. **Note:** This parameter is applicable only if MAC-DOT11-PC-POLL-SAVE is set to BY-COUNT.

Note: A Time Unit (TU) is equal to 1024 micro-seconds.

Table 4-6 shows infrastructure mode parameters for a station.

TABLE 4-6. 802.11 MAC Infrastructure Mode Parameters for a Station

Parameter	Value	Description
MAC-DOT11-STA-CHANNEL *Optional* *Scope:* All	Integer *Range:* ≥ 0	Specifies the index of the starting channel that the STA listens to for a dynamic association.
MAC-DOT11-SCAN-TYPE *Optional* *Scope:* All	List • DISABLED • ACTIVE • PASSIVE *Default:* DISABLED	Specifies the scanning method used by the STA when it is in dynamic association mode to discover an AP to associate with. DISABLED : No channel scanning. ACTIVE : Active probing of a channel to find an AP. PASSIVE : No probing. STA passively listens to channels for beacons. If MAC-DOT11-SCAN-TYPE is set to ACTIVE or PASSIVE, then the following parameters are also applicable: • MAC-DOT11-SCAN-MAX-CHANNEL-TIME • MAC-DOT11-STATION-HANDOVER-RSS-TRIGGER
MAC-DOT11-SCAN-MAX-CHANNEL-TIME *Optional* *Scope:* All	Integer *Range:* > 0 *Default:* (see note) *Unit:* TU	Maximum time a station waits on a channel for probe responses. **Note:** The default value is 24MS if MAC-DOT11-SCAN-TYPE is ACTIVE. The default value is 0 if MAC-DOT11-SCAN-TYPE is PASSIVE. **Note:** This parameter is applicable only MAC-DOT11-SCAN-TYPE is set to ACTIVE or PASSIVE.
MAC-DOT11-STATION-HANDOVER-RSS-TRIGGER *Optional* *Scope:* All	Real *Default:* (see note) *Unit:* dBm	Specifies the Handover Received Signal Strength (RSS) trigger. The STA tries to scan and re-associate with a neighbor AP if the RSS from the serving AP is below this threshold. **Note:** For 802.11a and 802.11b PHY model, the default value is the sum of 802.11 signal strength and 802.11 handover RSS margin. For PHY abstract model, default value is equal to RX sensitivity of the abstract model. **Note:** This parameter is applicable only MAC-DOT11-SCAN-TYPE is set to ACTIVE or PASSIVE.

TABLE 4-6. 802.11 MAC Infrastructure Mode Parameters for a Station (Continued)

Parameter	Value	Description
MAC-DOT11-STA-PS-MODE-ENABLED *Optional* *Scope:* All	List • YES • NO *Default:* NO	Specifies whether PS Mode is enabled or disabled at the STA. YES : PS mode is enabled for the STA. In this mode the STA will try to go in sleep mode when it is idle, if the associated AP also supports PS mode. The following parameters are also applicable: • MAC-DOT11-STA-PS-MODE-LISTEN-INTERVAL • MAC-DOT11-STA-PS-MODE-LISTEN-DTIM-FRAME NO : PS mode is disabled for the STA.
MAC-DOT11-STA-PS-MODE-LISTEN-INTERVAL *Optional* *Scope:* All	Integer *Range:* [0, 32767] *Default:* 10 *Unit:* beacon interval	Specifies the Listen interval. The listen interval is used to indicate to the AP how often an STA wakes to listen to beacon management frames.
MAC-DOT11-STA-PS-MODE-LISTEN-DTIM-FRAME *Optional* *Scope:* All	List • YES • NO *Default:* YES	Specifies whether the STA listens for DTIM frames. YES : STA receives DTIM frames from the AP. In this case, STAs change to awake state after expiration of either the listen interval or DTIM period. NO : STA changes to the awake state only after the expiration of the listen interval.
MAC-DOT11-STATION-POLL-TYPE *Optional* *Scope:* All	List • NOT-POLLABLE • POLLABLE-DONT-POLL • POLLABLE *Default:* POLLABLE	Specifies the Station behavior under CFP. NOT-POLLABLE : Station is not pollable. POLLABLE-DONT-POLL : The station is pollable but will not accept polls. POLLABLE : The station is pollable.
MAC-DOT11-STATION-PCF-STATISTICS *Optional* *Scope:* All	List • YES • NO *Default:* (see note)	Specifies whether PCF statistics are collected for stations. **Note:** The value of this parameter is YES for point coordination irrespective of what user has configured for this parameter, otherwise, the default value is NO.

4.1.4 GUI Configuration

This section describes how to configure 802.11 MAC in the GUI. Section 4.1.4.1 describes how to configure the general 802.11 MAC parameters. Section 4.1.4.2 describes the ad hoc mode configuration. Section 4.1.4.3 describes the infrastructure mode configuration. Section 4.1.4.4 describes how to enable statistics collection in the GUI.

Note: The default 802.11 MAC configuration is for ad hoc mode with both the power saving mode and the PCF procedure disabled.

4.1.4.1 General Configuration

To configure the general 802.11 MAC parameters, perform the following steps:

1. Go to one of the following locations:

- To set properties for a specific subnet, go to **Wireless Subnet Properties Editor > MAC Layer**.
- To set properties a specific interface of a node, go to one of the following locations:
  - **Interface Properties Editor > Interfaces > Interface # > MAC Layer**.
  - **Default Device Properties Editor > Interfaces > Interface # > MAC Layer**.

In this section, we show how to configure the general 802.11 MAC parameters in the Wireless Subnet Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **MAC Protocol** to *802.11* and set the dependent parameters listed in Table 4-7.

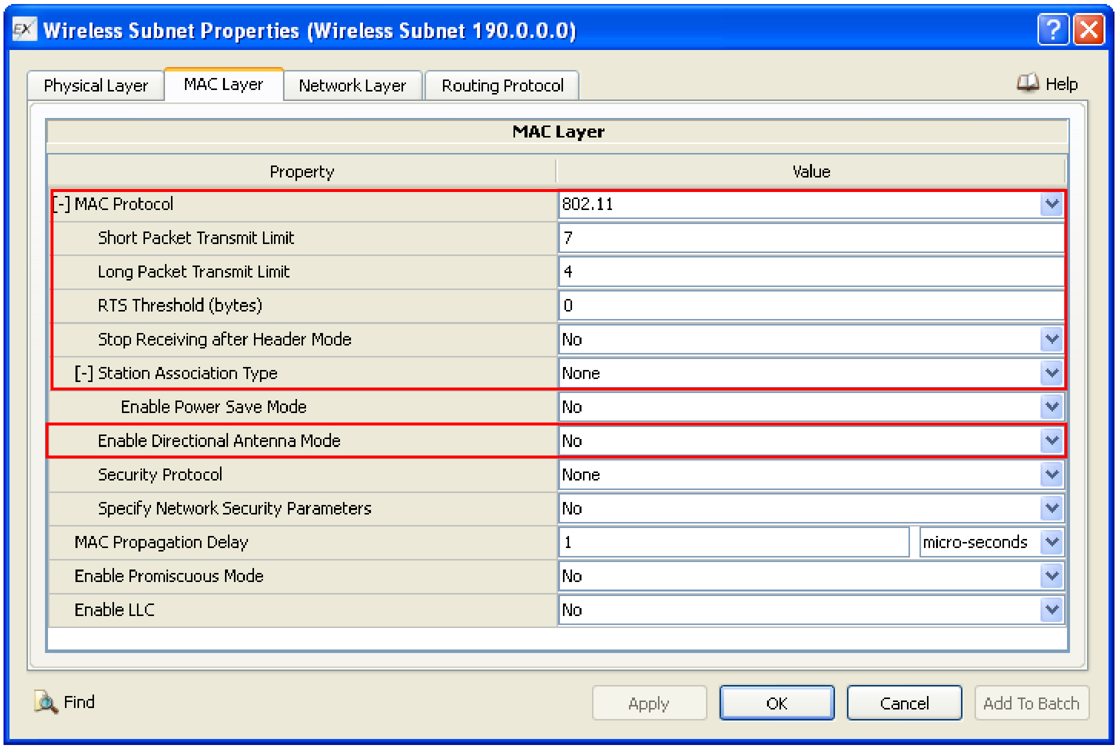


FIGURE 4-1. Selecting 802.11 MAC as MAC Protocol

TABLE 4-7. Command Line Equivalent of 802.11 MAC General Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Short Packet Transmit Limit	Subnet, Interface	MAC-DOT11-SHORT-PACKET-TRANSMIT-LIMIT
Long Packet Transmit Limit	Subnet, Interface	MAC-DOT11-SHORT-PACKET-TRANSMIT-LIMIT
RTS Threshold	Subnet, Interface	MAC-DOT11-RTS-THRESHOLD
Stop Receiving after Header Mode	Subnet, Interface	MAC-DOT11-STOP-RECEIVING-AFTER-HEADER-MODE
Station Association Type	Subnet, Interface	MAC-DOT11-ASSOCIATION
Enable Directional Antenna Mode	Subnet, Interface	MAC-DOT11-DIRECTIONAL-ANTENNA-MODE

Setting Parameters

- To enable directional antenna mode, set **Directional Antenna Mode** to *Yes*; otherwise, set **Directional Antenna Mode** to *No*.
- To enable the ad hoc mode, set **Station Association Type** to *None* and configure the ad hoc mode parameters, as described in Section 4.1.3.2.
- To enable the infrastructure mode, set **Station Association Type** to *Dynamic* and configure the infrastructure mode parameters, as described in Section 4.1.3.3.

3. If **Directional Antenna Mode** is set to *Yes*, set the dependent parameters listed in Table 4-8.

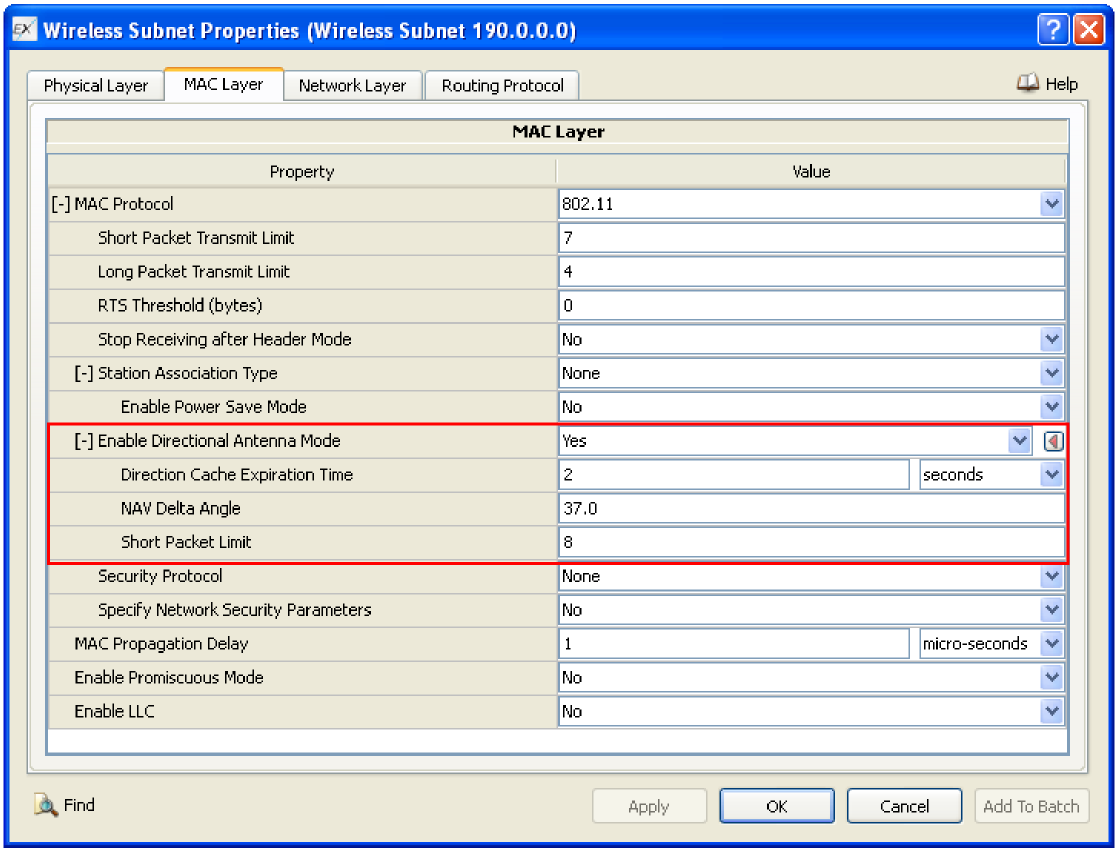


FIGURE 4-2. Configuring Directional Antenna Mode

TABLE 4-8. Command Line Equivalent of Directional Antenna Mode Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Direction Cache Expiration Time	Subnet, Interface	`MAC-DOT11-DIRECTION-CACHE-EXPIRATION-TIME`
NAV Delta Angle	Subnet, Interface	`MAC-DOT11-DIRECTIONAL-NAV-AOA-DELTA-ANGLE`
Short Packet Limit	Subnet, Interface	`MAC-DOT11-DIRECTIONAL-SHORT-PACKET-TRANSMIT-LIMIT`

4.1.4.2 Ad Hoc Mode Configuration

The ad hoc mode can be selected at both the interface and subnet levels. The power save mode in ad hoc mode can be configured only at the subnet level.

In this section, we show how to configure the ad hoc mode parameters in the Wireless Subnet Properties Editor. Applicable parameters can be set in the other properties editors in a similar way.

To configure the 802.11 MAC ad hoc mode parameters in the GUI, perform the following steps:

1. Set the general 802.11 MAC parameters, as described in Section 4.1.4.1.
2. Set **MAC Protocol** *[= 802.11]* **> Station Association Type** to *None* and set the dependent parameters listed in Table 4-9.

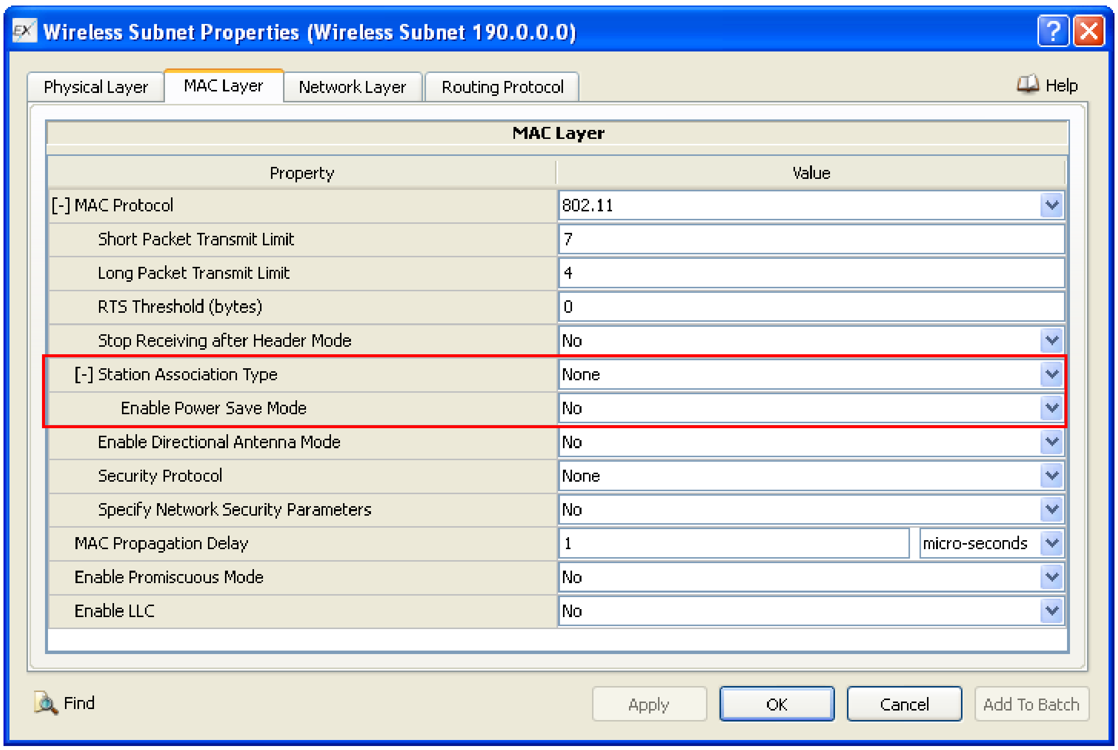


FIGURE 4-3. Setting Ad Hoc Mode Parameters

TABLE 4-9. Command Line Equivalent of Ad Hoc Mode Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Enable Power Save Mode	Subnet	`MAC-DOT11-IBSS-SUPPORT-PS-MODE`

Setting Parameters

- To enable power save mode, set **Enable Power Save Mode** to *Yes*; otherwise, set **Enable Power Save Mode** to *No*.
- All nodes in an IBSS should have **Enable Power Save Mode** set to the same value.

3. If **Enable Power Save Mode** is set to *Yes*, set the dependent parameters listed in Table 4-10.

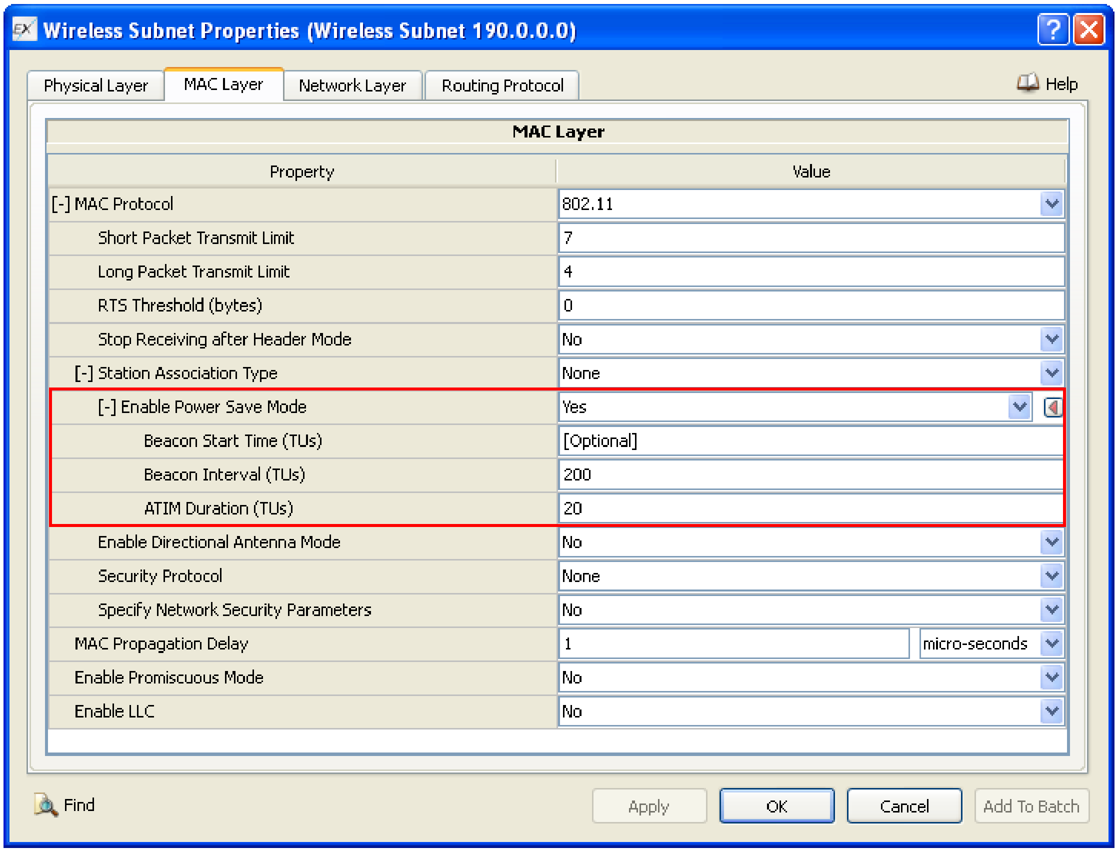


FIGURE 4-4. Configuring Power Save Mode in Ad Hoc Mode

TABLE 4-10. Command Line Equivalent of Power Save Mode in Ad Hoc Mode Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Beacon Start Time	Subnet	`MAC-DOT11-IBSS-BEACON-START-TIME`
Beacon Interval	Subnet	`MAC-DOT11-IBSS-BEACON-INTERVAL`
ATIM Duration	Subnet	`MAC-DOT11-IBSS-PS-MODE-ATIM-DURATION`

4.1.4.3 Infrastructure Mode Configuration

The infrastructure mode can be selected at both the interface and subnet levels. The access point can be configured only at the interface level.

In this section, we show how to configure the ad hoc mode parameters in the Interface Properties Editor. Applicable parameters can be set in the other properties editors in a similar way.

To configure the 802.11 MAC infrastructure mode parameters, perform the following steps:

1. Set the general 802.11 MAC parameters, as described in Section 4.1.4.1.
2. Set **MAC Protocol** *[= 802.11]* **> Station Association Type** to *Dynamic* and set the dependent parameters listed in Table 4-11.

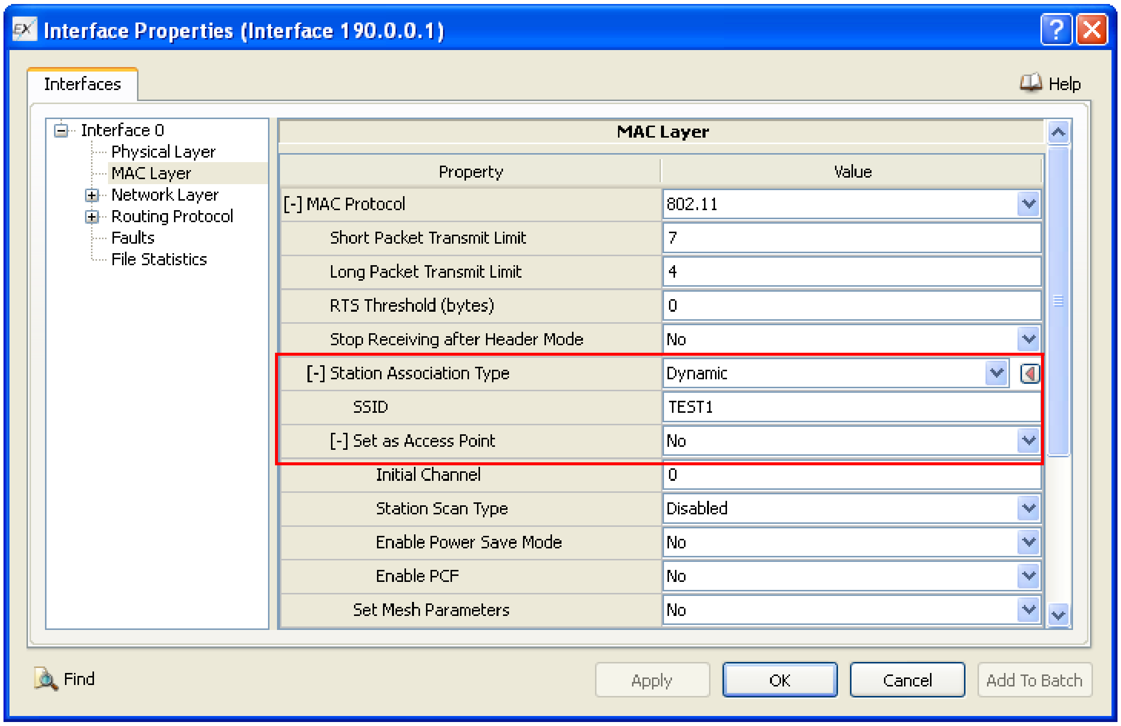


FIGURE 4-5. Configuring Infrastructure Mode parameters

TABLE 4-11. Command Line Equivalent of Infrastructure Mode Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
SSID	Subnet, Interface	`MAC-DOT11-SSID`
Set as Access Point	Subnet, Interface	`MAC-DOT11-AP`

Setting Parameters

- To configure the node as a station, set **Set as Access Point** to *No*. To configure the node as an access point, set **Set as Access Point** to *Yes*. Configure the parameters for access points and stations as described below.
- For a station to associate with an access point, **SSID** should be set to the same value for both the station and the access point.

Infrastructure Mode Configuration for an Access Point

To configure a node as an access point, perform the following steps:

1. Set **MAC Protocol** *[= 802.11]* **> Station Association Type** *[= Dynamic]* **> Set as Access Point** to *Yes* and set the dependent parameters listed in Table 4-12.

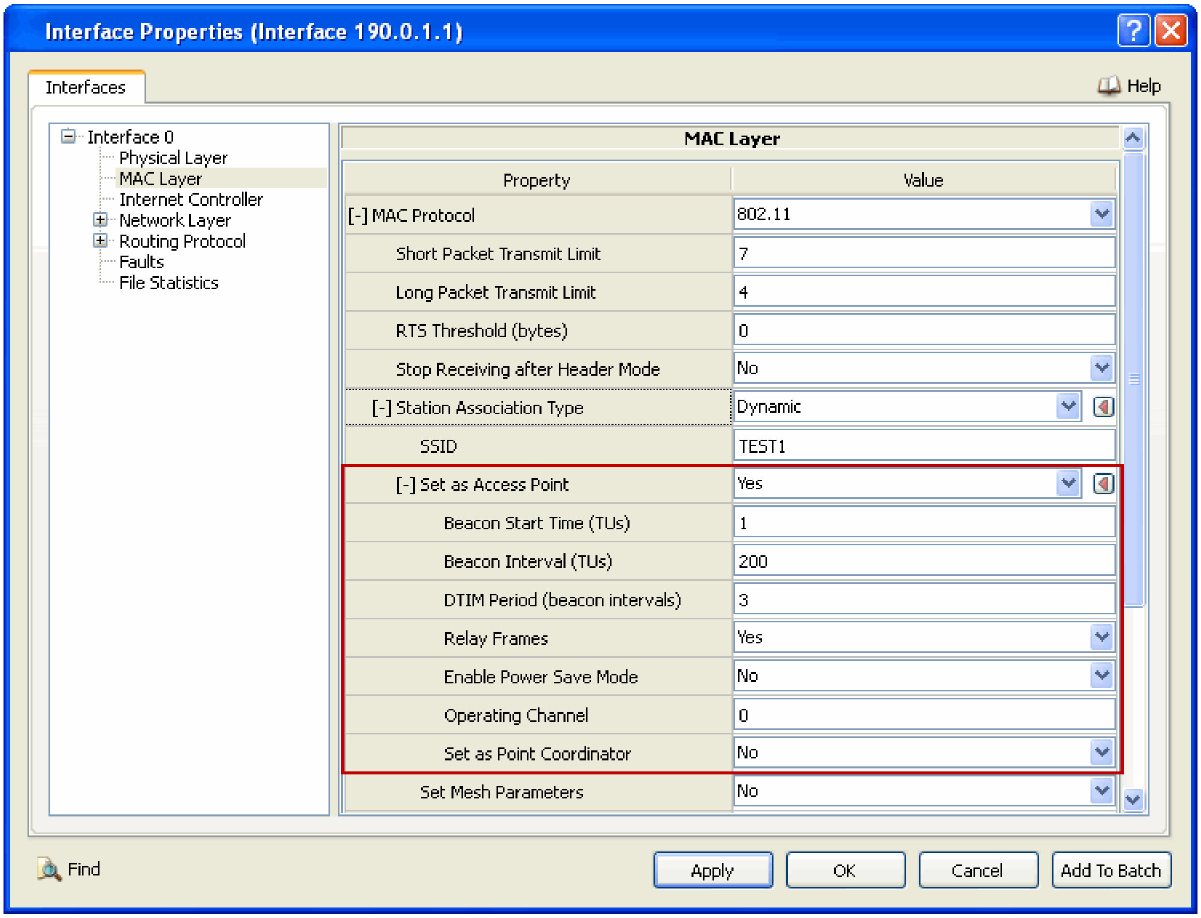


FIGURE 4-6. Configuring Access Point Parameters

TABLE 4-12. Command Line Equivalent of Access Point Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Beacon Start Time	Subnet, Interface	`MAC-DOT11-BEACON-START-TIME`
Beacon Interval	Subnet, Interface	`MAC-DOT11-BEACON-INTERVAL`
DTIM Period	Subnet, Interface	`MAC-DOT11-DTIM-PERIOD`
Relay Frames	Subnet, Interface	`MAC-DOT11-RELAY-FRAMES`
Enable Power Save Mode	Subnet, Interface	`MAC-DOT11-AP-SUPPORT-PS-MODE`
Operating Channel	Subnet, Interface	`MAC-DOT11-STA-CHANNEL`
Set as Point Coordinator	Subnet, Interface	`MAC-DOT11-PC`

Setting Parameters

- To enable power save mode, set **Enable Power Save Mode** to *Yes*; otherwise, set **Enable Power Save Mode** to *No*.
- To enable the PCF procedure for an access point, set **Set as Point Coordinator** to *Yes*.

2. If **Set as Point Coordinator** is set to *Yes*, then set the PCF parameters listed in Table 4-13.

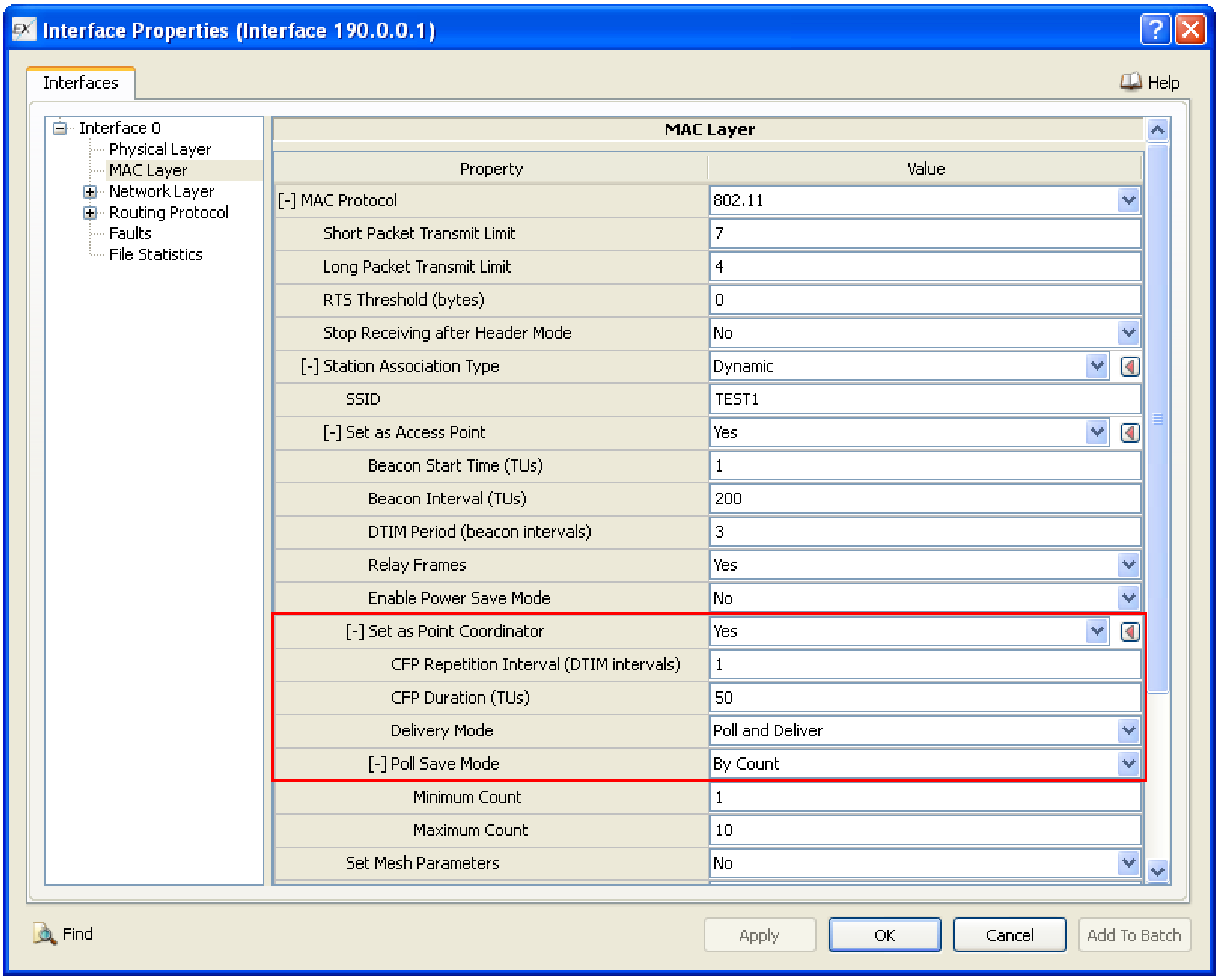


FIGURE 4-7. Configuring PCF Procedure for an Access Point

TABLE 4-13. Command Line Equivalent of PCF Parameters for an Access Point

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
CFP Repetition Interval	Subnet, Interface	`MAC-DOT11-PC-CF-REPETITION-INTERVAL`
CFP Duration	Subnet, Interface	`MAC-DOT11-PC-CF-DURATION`
Delivery Mode	Subnet, Interface	`MAC-DOT11-PC-DELIVERY-MODE`
Poll Save Mode	Subnet, Interface	`MAC-DOT11-PC-POLL-SAVE`

Setting Parameters

- To enable poll save mode, set **Poll Save Mode** to *By Count*; otherwise, set **Poll Save Mode** to *None*.

3. If **Poll Save Mode** is set to *By Count*, set the dependent parameters listed in Table 4-14.

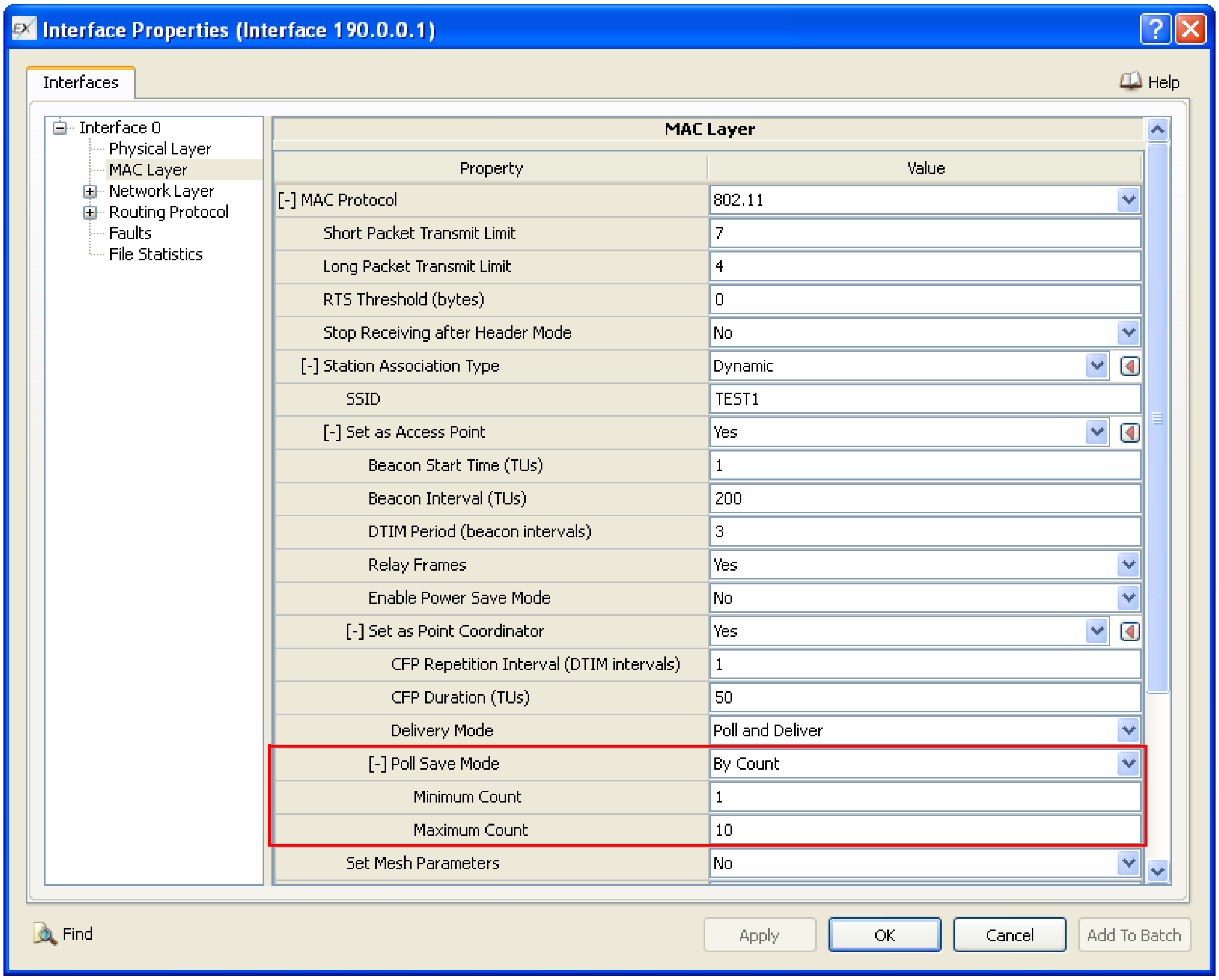


FIGURE 4-8. Configuring By Count Poll Save Mode Parameters

TABLE 4-14. Command Line Equivalent of By Count Poll Save Mode Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Min Count	Subnet, Interface	`MAC-DOT11-PC-POLL-SAVE-MIN`
Max Count	Subnet, Interface	`MAC-DOT11-PC-POLL-SAVE-MAX`

Infrastructure Mode Configuration for a Station

To configure a node as a station, perform the following steps:

1. Set **MAC Protocol** *[= 802.11]* **> Station Association Type** *[= Dynamic]* **> Set as Access Point** to *No* and set the dependent parameters listed in Table 4-15.

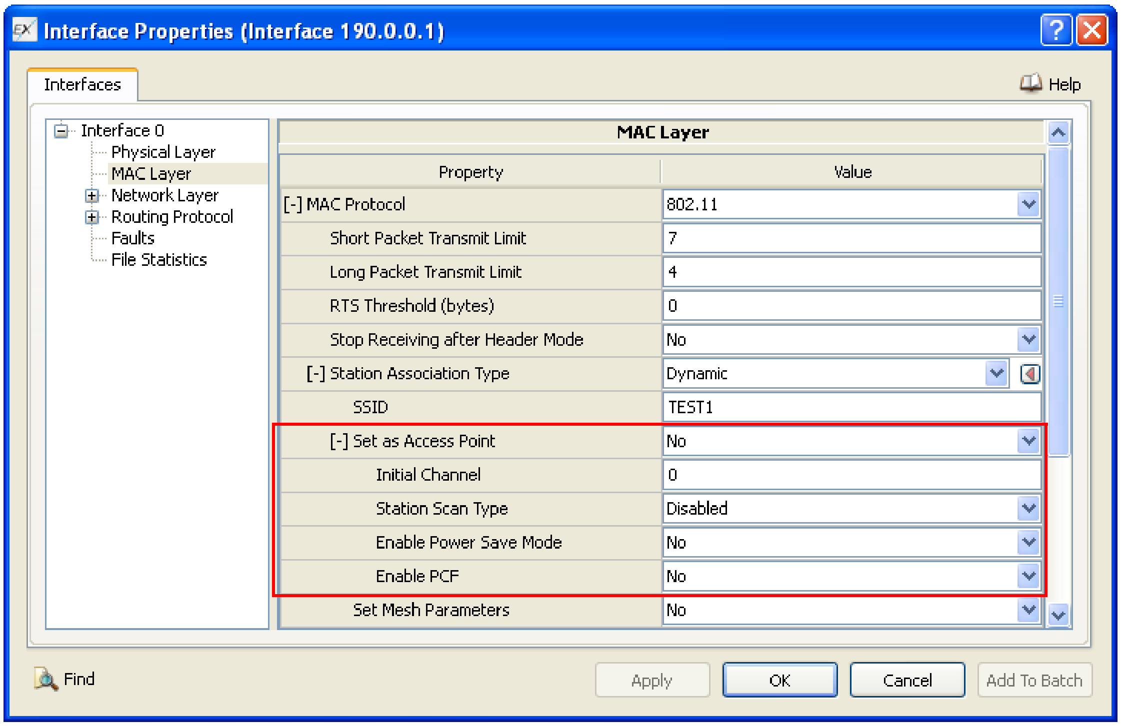


FIGURE 4-9. Setting Station Parameters for Infrastructure Mode.

TABLE 4-15. Command Line Equivalent of Infrastructure Mode Parameters for a Station

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Initial Channel	Subnet, Interface	`MAC-DOT11-STA-CHANNEL`
Station Scan Type	Subnet, Interface	`MAC-DOT11-SCAN-TYPE`
Enable Power Save Mode	Subnet, Interface	`MAC-DOT11-STA-PS-MODE-ENABLED`
Enable PCF	Subnet, Interface	`N/A`

Setting Parameters

- To enable searching for an access point by scanning, set **Station Scan Type** to *Active* or *Passive*; otherwise, set **Station Scan Type** to *Disabled*.
- To enable power save mode, set **Enable Power Save Mode** to *Yes*; otherwise, set **Enable Power Save Mode** to *No*.
- To enable the PCF procedure for the station, set **Enable PCF** to *Yes*; otherwise, set **Enable PCF** to *No*.

2. If **Station Scan Type** is set to *Active* or *Passive*, set the dependent parameters listed in Table 4-16.

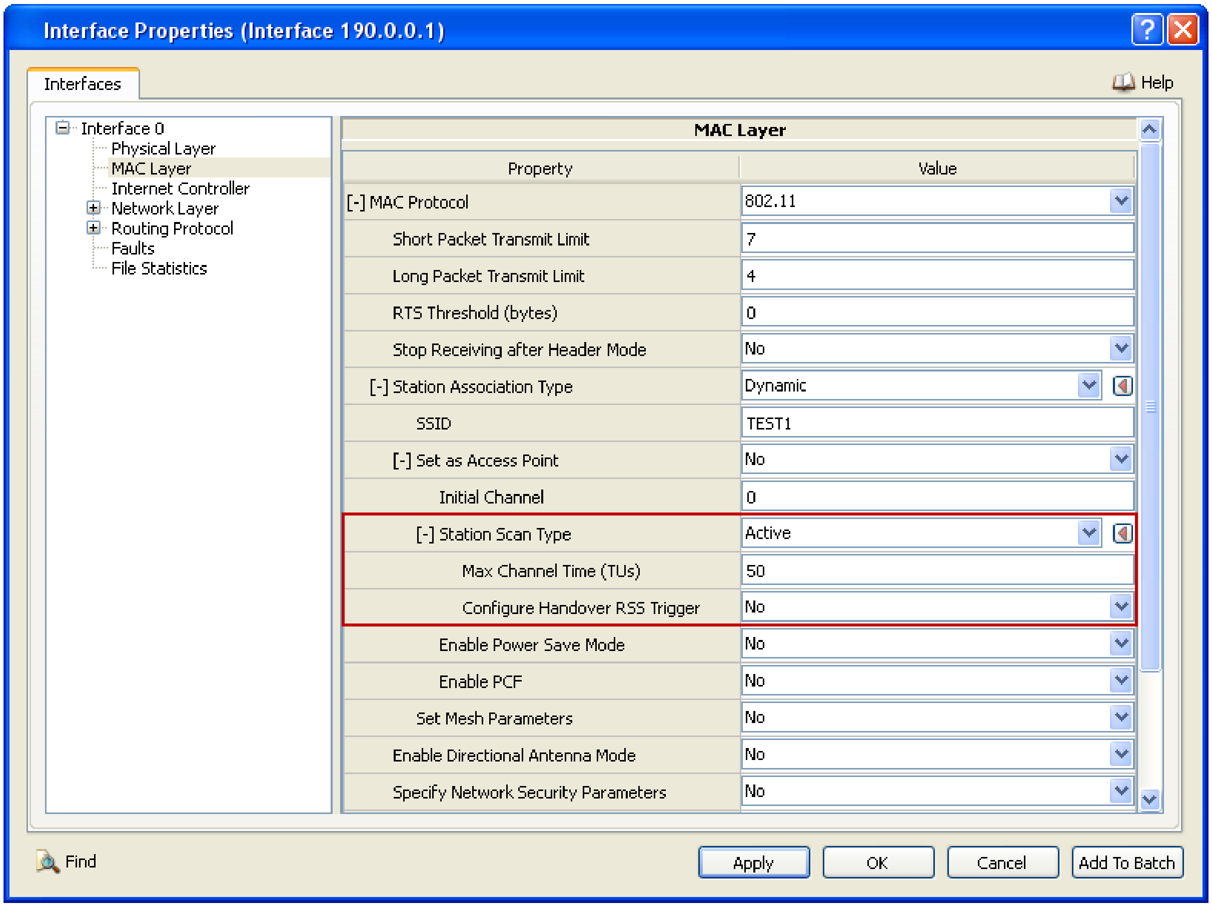


FIGURE 4-10. Configuring Passive Scan Parameters

TABLE 4-16. Command Line Equivalent of Passive Scan Type Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Max Channel Time	Subnet, Interface	`MAC-DOT11-SCAN-MAX-CHANNEL-TIME`
Configure Handover RSS Trigger	Subnet, Interface	N/A

Setting Parameters

- To specify a handover RSS trigger, set **Configure Handover RSS Trigger** to *Yes*. To use the default value for the trigger, set **Configure Handover RSS Trigger** to *No*.

3. If **Configure Handover RSS Trigger** is set to *Yes*, set the dependent parameters listed in Table 4-17.

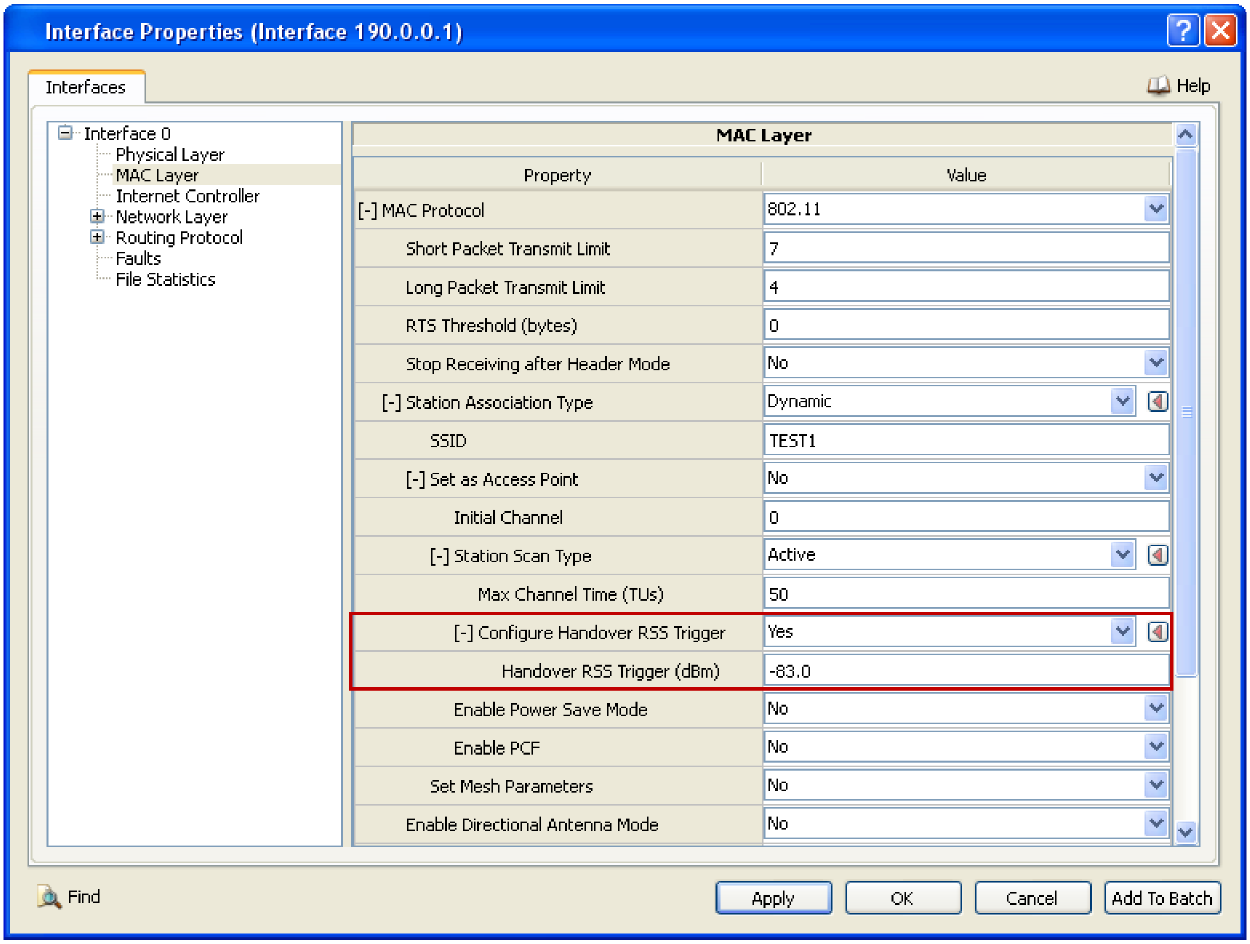


FIGURE 4-11. Configuring Handover RSS Trigger Parameters

TABLE 4-17. Command Line Equivalent of Handover RSS Trigger Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Handover RSS Trigger	Subnet, Interface	`MAC-DOT11-STATION-HANDOVER-RSS-TRIGGER`

4. If **MAC Protocol** *[= 802.11]* **> Station Association Type** *[= Dynamic]* **> Set as Access Point** *[= No]* **> Enable Power Save Mode** is set to *Yes*, set the dependent parameters listed in Table 4-18.

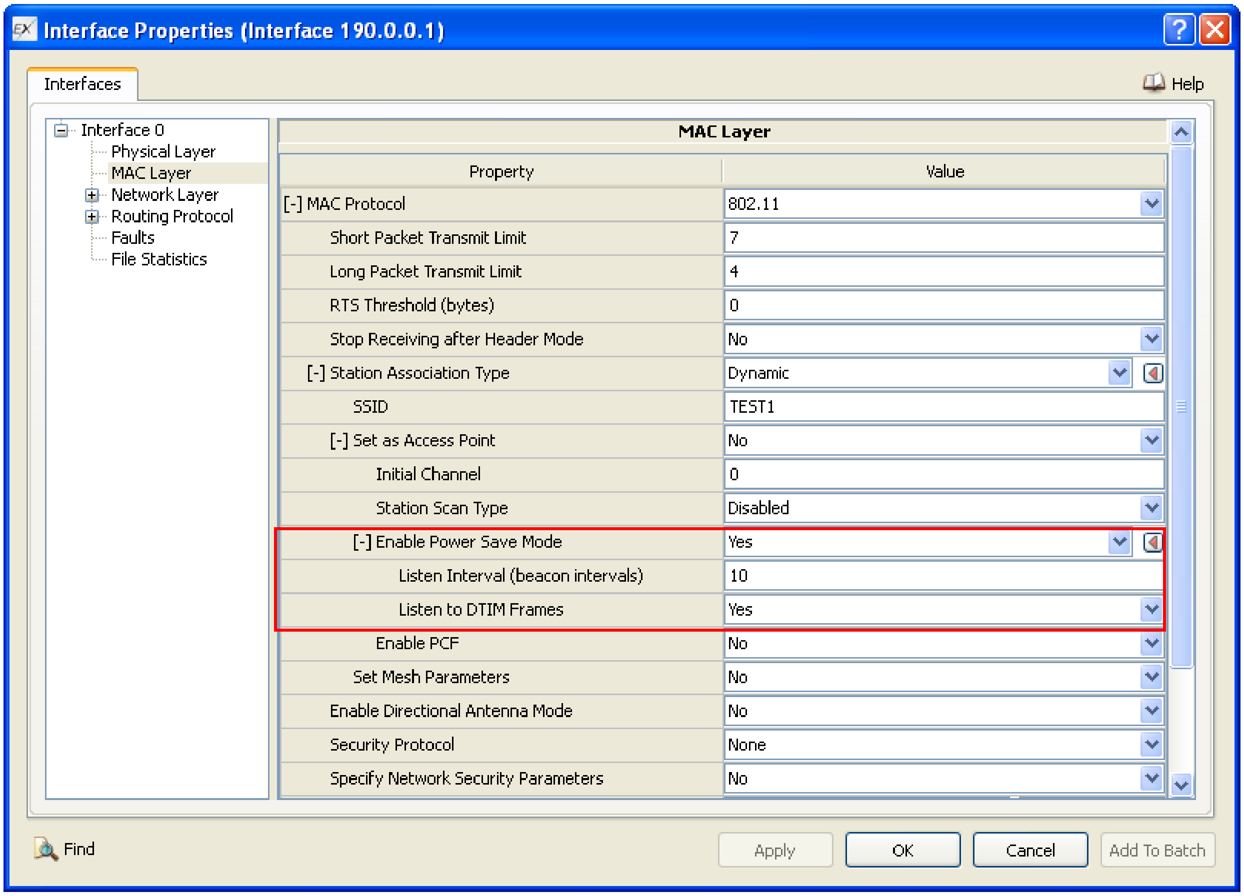


FIGURE 4-12. Configuring Power Save Mode Parameters for a Station

TABLE 4-18. Command Line Equivalent of Power Save Mode Parameters for a Station

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Listen Interval	Subnet, Interface	`MAC-DOT11-STA-PS-MODE-LISTEN-INETRVAL`
Listen to DTIM Frames	Subnet, Interface	`MAC-DOT11-STA-PS-MODE-LISTEN-DTIM-FRAME`

5. If **MAC Protocol** *[= 802.11]* **> Station Association Type** *[= Dynamic]* **> Set as Access Point** *[= No]* **> Enable PCF** is set to *Yes*, then set the PCF parameters listed in Table 4-19.

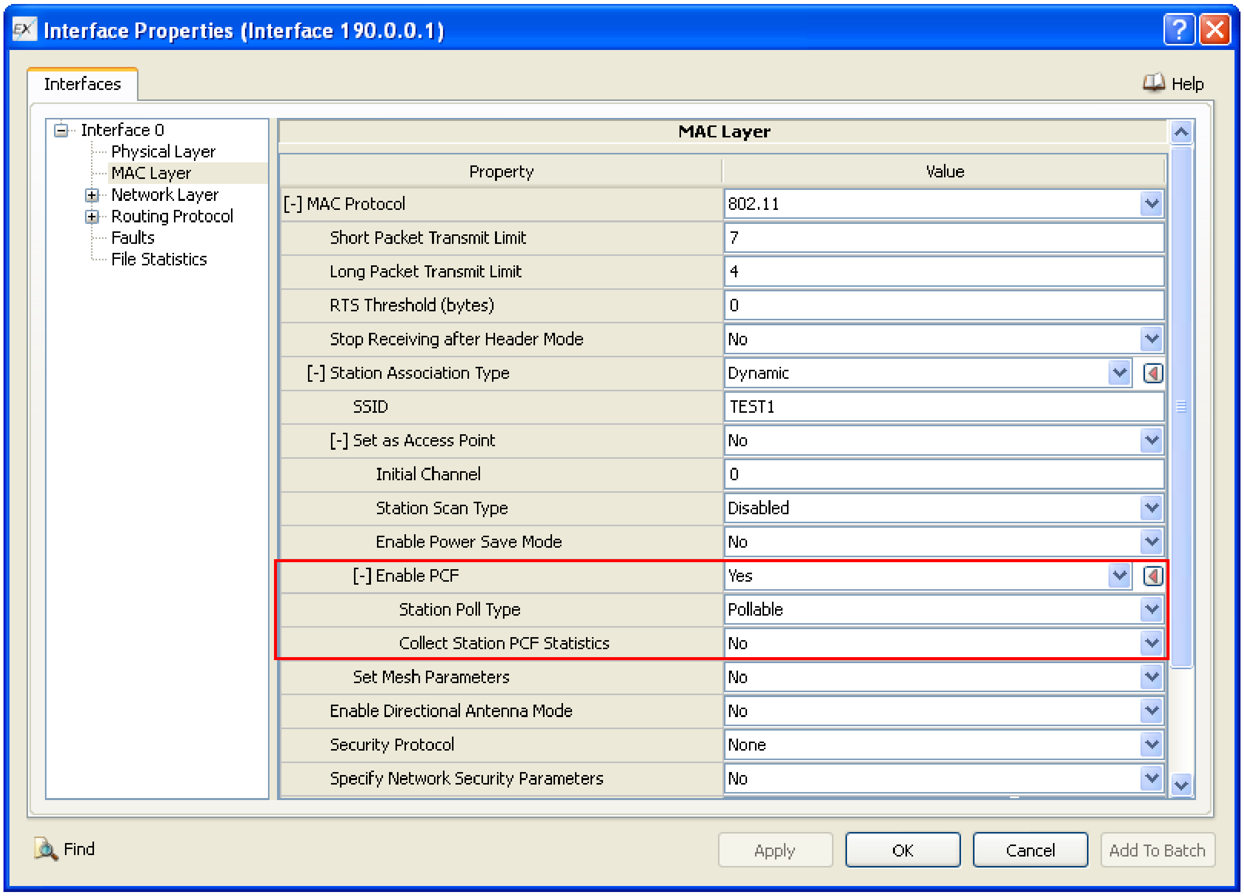


FIGURE 4-13. Configuring PCF Procedure for a Station

TABLE 4-19. Command Line Equivalent of PCF Parameters for a Station

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Station Poll Type	Subnet, Interface	MAC-DOT11-STATION-POLL-TYPE
Collect Station PCF Statistics	Subnet, Interface	MAC-DOT11-STATION-PCF-STATISTICS

4.1.4.4 Configuring Statistics Parameters

Statistics for 802.11 MAC can be collected at the global, node, subnet, and interface levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for MAC protocols including 802.11 MAC, check the box labeled **MAC** in the appropriate properties editor.

TABLE 4-20. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
MAC	Global, Node, Subnet, Interface	`MAC-LAYER-STATISTICS`

4.1.5 Statistics

This section describes the file, database, and dynamic statistics of the 802.11 MAC model.

4.1.5.1 File Statistics

This section describes the 802.11 MAC statistics that are output to the statistics (.stat) file at the end of simulation.

Table 4-21 shows the general 802.11 MAC statistics.

TABLE 4-21. 802.11 MAC General Statistics

Statistic	Description
Packets from network	Total number of packets received from network layer.
Unicast packets sent to channel	Total number of unicast packets send to the channel.
Broadcast packets sent to channel	Total number of broadcast packets send to the channel.
Unicast packets received clearly	Total number of unicast packets received form the channel.
Broadcast packets received clearly	Total number of broadcast packets received from the channel.
Unicasts sent	Total number of successful unicast packets sent to the channel.
Broadcasts sent	Total number of successful broadcast packets sent to the channel.
Unicasts received	Total number of successful unicast packets received from the channel.
Broadcasts received	Total number of successful broadcast packets received from the channel.
CTS packets sent	Total number of CTS packets send to the channel.
RTS packets sent	Total number of RTS packets send to the channel.
ACK packets sent	Total number of ACK packets sent.
RTS retransmissions due to timeout	Total number of RTS retransmissions due to timeout.
Packet retransmissions due to ACK timeout	Total number of data retransmissions due to no ACK received.
Packet drops due to retransmission limit	Total number of packets dropped due to retry limit exceeds.

Table 4-22 shows the 802.11 MAC for a station in ad hoc mode.

TABLE 4-22. 802.11 MAC Ad Hoc Mode Statistics for a Station

Statistic	Description
Management ATIM Frames Sent	Total number of management ATIM frames transmitted to other STAs.
Management ATIM Frames Received	Total number of management ATIM frames received from other STAs.

TABLE 4-22. 802.11 MAC Ad Hoc Mode Statistics for a Station (Continued)

Statistic	Description
PS Mode Broadcast Data Packets Sent	Total number of broadcast data packets sent in PS mode.
PS Mode Unicast Data Packets Sent	Total number of unicast data packets sent in PS mode.
MAC Layer Queue Drop Packet	Total number of MAC layer queue packet drops due to aging function.

Table 4-23 shows the 802.11 MAC infrastructure mode statistics for an access point.

TABLE 4-23. 802.11 MAC Infrastructure Mode Statistics for an Access Point

Statistic	Description
Management packets sent to channel	Total number of management packets sent to the channel.
Management packets received from channel	Total number of management packets received from the channel.
Beacons received	Total number of beacon frames received.
Beacons sent	Total number of beacon frames sent.
Management probe request send	Total Management probe request send.
Management probe request received	Total Management probe request received.
Management probe response send	Total Management probe response send.
Management probe response received	Total Management probe response received.
Management probe response dropped	Total Management probe response dropped.
Management authentication request send	Total Management authentication request send.
Management authentication request received	Total Management authentication request received.
Management authentication request dropped	Total Management authentication request dropped.
Management authentication response send	Total Management authentication response send.
Management authentication response received	Total Management authentication response received.
Management authentication response dropped	Total Management authentication response dropped.
Management association requests send	Total Management association requests send.
Management association requests received	Total Management association requests received.
Management association requests dropped	Total Management association requests dropped.
Management association response send	Total Management association response send.
Management association response received	Total Management association response received.
Management association response dropped	Total Management association response dropped.
Management reassociation requests send	Total Management reassociation requests send.
Management reassociation requests received	Total Management reassociation requests received.
Management reassociation requests dropped	Total Management reassociation requests dropped.Total Management reassociation requests dropped.
Management reassociation response send	Total Management reassociation response send.
Management reassociation response received	Total Management reassociation response received.
Management reassociation response dropped	Total Management reassociation response dropped.

Table 4-24 shows the 802.11 MAC statistics for a station in infrastructure mode.

TABLE 4-24. 802.11 MAC Infrastructure Mode Statistics for a Station

Statistic	Description
PS Poll Requests Sent	Total number of PS poll request frames sent in PS mode.
PS Mode DTIM Frames Received	Total number of DTIM frames received in PS mode.
PS Mode TIM Frames Received	Total number of TIM frames received in PS mode.
PS Mode Unicast Data packets Sent	Total number of unicast data packets transmitted in PS mode.
PS Mode Broadcast Data packets Sent	Total number of broadcast data packets transmitted in PS mode.
MAC Layer Queue Drop Packet	Total number of packet drops at due to aging function.
PS Mode DTIM Frames Sent	Total number of DTIM frames sent in PS mode.
PS Mode TIM Frames Sent	Total number of TIM frames sent in PS mode.
PS Poll Requests Received	Total number of poll requests received in PS mode.

Table 4-25 shows the 802.11 MAC PCF procedure statistics for a point coordinator.

TABLE 4-25. 802.11 MAC PCF Procedure Statistics for a Point Coordinator

Statistic	Description
Unicasts sent and Acked	Total number of unicast packets sent and acknowledged from the channel.
Broadcasts sent	Total number of broadcast packets sent by PC in the channel.
Unicasts received	Total number of unicast packets received from channel.
Broadcasts received	Total number of broadcast packets received from Channel.
Data-Polls transmitted	Total number of data-polls transmitted.
Polls transmitted	Total number of Polls transmitted.
Data packets transmitted	Total number of data packets transmitted.
Data packets received	Total number of data packets received.
NullData received	Total number of null data packets received.
CF Ends transmitted	Total number of CF Ends transmitted.
CF Ends received	Total number of CF Ends received.
Beacons transmitted	Total number of Beacons transmitted.
Beacons received	Total number of Beacons received.

Table 4-26 shows the 802.11 MAC PCF procedure statistics for a station.

TABLE 4-26. 802.11 MAC PCF Procedure Statistics for a Station

Statistic	Description
Unicasts sent and Acked	Total number of unicast packets sent and acknowledged from channel.
Unicasts received	Total number of unicast packets received from channel.
Broadcasts received	Total number of broadcast packets received from channel.
Data packets transmitted	Total number of data packets transmitted to channel.
NullData transmitted	Total number of null data packets transmitted to the channel.

TABLE 4-26. 802.11 MAC PCF Procedure Statistics for a Station (Continued)

Statistic	Description
Data-Polls received	Total number of data-polls received.
Polls received	Total number of polls received.
Data packets received	Total number of data packets received.
Beacons received	Total number of beacons received.
CF Ends Received	Total number of CF Ends Received.

4.1.5.2 Database Statistics

In addition to the file statistics, the 802.11 MAC model also enters statistics in various scenario statistics database tables. Refer to *EXata Statistics Database User's Guide* for details.

4.1.5.3 Dynamic Statistics

No dynamic statistics are supported for the 802.11 MAC model.

4.1.6 Sample Scenarios

This section describes two sample scenarios:

- Ad hoc mode
- Infrastructure mode

4.1.6.1 Sample Scenario for Ad Hoc Mode

4.1.6.1.1 Scenario Description

The sample scenario creates an 802.11 network running in ad hoc mode with power saving enabled. The scenario contains six nodes, nodes 1 to 6, running 802.11 MAC.

Topology

Figure 4-14 shows the sample scenario topology.

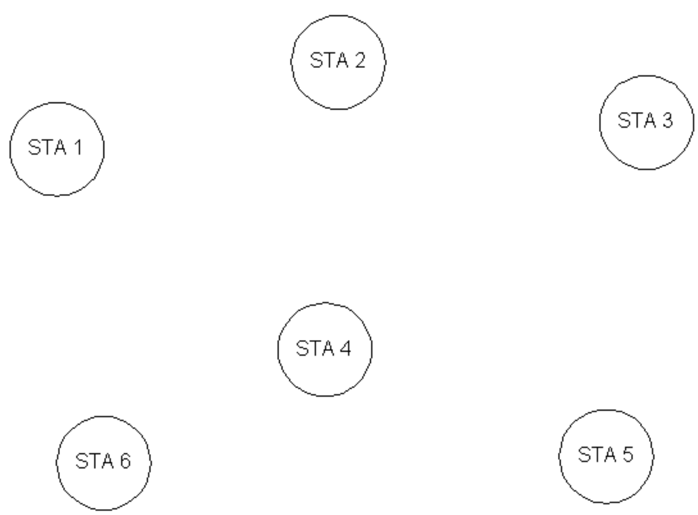


FIGURE 4-14. Ad Hoc Mode Sample Scenario Topology

4.1.6.1.2 Command Line Configuration

To configure the sample scenario for the command line, include the following lines in the scenario configuration (.config) file:

```
SUBNET N8-192.0.0.0 { 1 thru 6 }

# Select 802.11 as the MAC protocol and set the DCF procedure
# parameters.

[ N8-192.0.0.0 ] MAC-PROTOCOL                                  MACDOT11
[ N8-192.0.0.0 ] MAC-MAC-DOT11-SHORT-PACKET-TRANSMIT-LIMIT        6
[ N8-192.0.0.0 ] MAC-MAC-DOT11-SHORT-PACKET-TRANSMIT-LIMIT        3
[ N8-192.0.0.0 ] MAC-MAC-DOT11-RTS-THRESHOLD                      128
[ N8-192.0.0.0 ] MAC-MAC-DOT11-STOP-RECEIVING-AFTER-HEADER-MODE   NO

# Select directional antenna mode and set the dependent parameters.

[ N8-192.0.0.0 ] MAC-MAC-DOT11-DIRECTIONAL-ANTENNA-MODE             YES
[ N8-192.0.0.0 ] MAC-MAC-DOT11-DIRECTION-CACHE-EXPIRATION-TIME      10S
[ N8-192.0.0.0 ] MAC-MAC-DOT11-DIRECTIONAL-NAV-AOA-DELTA-ANGLE      45

# Select the ad hoc mode, enable power saving mode and set the
# dependent parameters.

[ N8-192.0.0.0 ] MAC-DOT11-ASSOCIATION                         NONE
[ N8-192.0.0.0 ] MAC-DOT11-IBSS-SUPPORT-PS-MODE                YES
[ N8-192.0.0.0 ] MAC-DOT11-IBSS-BEACON-START-TIME              1
[ N8-192.0.0.0 ] MAC-DOT11-IBSS-BEACON-INTERVAL                200
[ N8-192.0.0.0 ] MAC-DOT11-IBSS-PS-MODE-ATIM-DURATION          20
```

4.1.6.1.3 GUI Configuration

Perform the following steps to create this sample scenario using the GUI:

1. Place six nodes of the Default device type and a wireless subnet on the canvas. Connect all six nodes to the wireless subnet.
2. Go to the MAC layer tab of the Wireless Subnet Properties Editor and set **MAC Protocol** to *802.11*. See Figure 4-15.

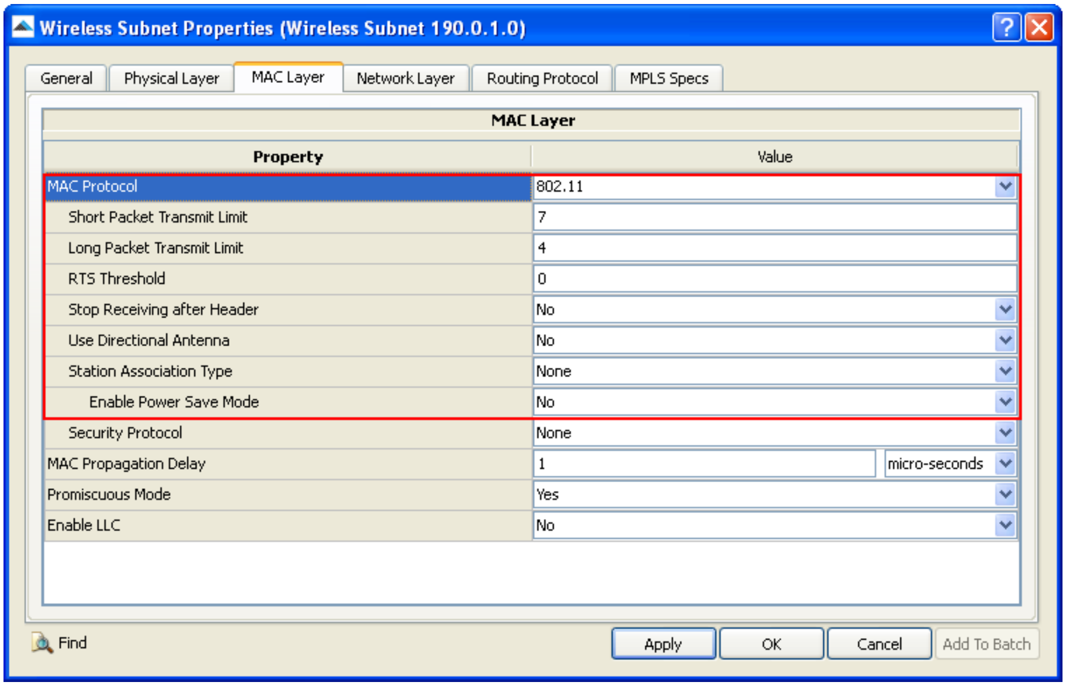


FIGURE 4-15. Setting MAC Protocol to 802.11 for a Subnet

3. Set **Station Association Type** to *None*. See Figure 4-3.
4. Set **Enable Power Save Mode** to *Yes* and set the dependent parameters. See Figure 4-4

4.1.6.2 Sample Scenario for Infrastructure Mode

4.1.6.2.1 Scenario Description

The sample scenario creates an 802.11 network running in infrastructure mode. The scenario contains six nodes, nodes 1 to 6. Node 1 is an access point and nodes 2 to 6 are stations. Nodes 1, 2, 3, and 4 have power saving enabled.

Topology

Figure 4-16 shows the sample scenario topology.

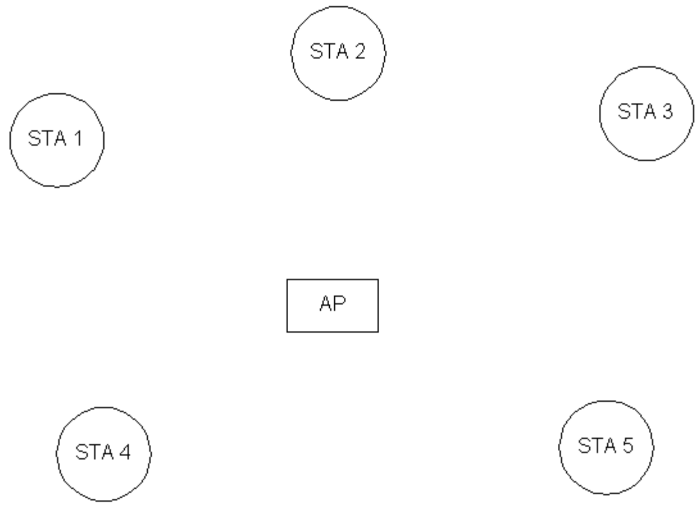


FIGURE 4-16. Infrastructure Mode Sample Scenario Topology

4.1.6.2.2 Command Line Configuration

To configure the sample scenario for the command line, include the following lines in the scenario configuration (.config) file:

```
SUBNET N8-192.0.0.0 { 1 thru 6 }

# Select 802.11 as the MAC protocol. Select the infrastructure mode and
# set the dependent parameters.
#
[ N8-192.0.0.0 ] MAC-PROTOCOL                                    MACDOT11
[ N8-192.0.0.0 ] MAC-DOT11-ASSOCIATION                           DYNAMIC
[ N8-192.0.0.0 ] MAC-DOT11-SCAN-TYPE                             PASSIVE
[ N8-192.0.0.0 ] MAC-DOT11-SSID                                  TEST1
[ N8-192.0.0.0 ] MAC-DOT11-STA-CHANNEL                           1

# Configure node 1 as an access point. Enable power saving and set the
# dependent parameters.

[ 1 ] MAC-DOT11-AP                                               YES
[ 1 ] MAC-DOT11-DTIM-PERIOD                                      3
[ 1 ] MAC-DOT11-AP-SUPPORT-PS-MODE                               YES
[ 1 ] MAC-DOT11-BEACON-START-TIME                                1
[ 1 ] MAC-DOT11-BEACON-INTERVAL                                  200
[ 1 ] MAC-DOT11-RELAY-FRAMES                                     YES

# Nodes 2 through 6 are stations. For nodes 2 through 4, enable power
# saving, set the dependent parameters.

[ 2 thru 4 ] MAC-DOT11-STA-PS-MODE-ENABLED                       YES
[ 2 thru 4 ] MAC-DOT11-STA-PS-MODE-LISTEN-INTERVAL               10
[ 2 thru 4 ] MAC-DOT11-STA-PS-MODE-LISTEN-DTIM-FRAME             YES
```

4.1.6.2.3 GUI Configuration

Perform the following steps to create this sample scenario using the GUI:

1. Place six nodes of the Default device type and a wireless subnet on the canvas. Connect all six nodes to the wireless subnet.
2. To configure node 1 (AP), do the following:
   a. Go to the Interface Properties Editor and select Interfaces **>** Interface # **>** MAC Layer.
   b. Set **MAC Protocol** to *802.11*. See Figure 4-1.
   c. Set **Station Association Type** to *Dynamic*. See Figure 4-5.
   d. Set **Set as Access Point** to *Yes*. See Figure 4-6.
   e. Set **Enable Power Save Mode** to *Yes*. See Figure 4-6.
3. To configure nodes 2 through 6 (stations), do the following:
   a. Go to the Interface Properties Editor and select Interfaces **>** Interface # **>** MAC Layer.
   b. Set **MAC Protocol** to *802.11*. See Figure 4-1.
   c. Set **Station Association Type** to *Dynamic*. See Figure 4-5.
   d. Set **Set as Access Point** to *No*. See Figure 4-9.

e. For nodes 2, 3, and 4, set **Enable Power Save Mode** to *Yes* and set the dependent parameters listed in Table 4-18. See Figure 4-12.

f. For nodes 5 and 6, set **Enable Power Save Mode** to *No*. See Figure 4-9.

4.1.7 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the 802.11 MAC protocol. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/dot11. Table 4-27 lists the sub-directory where each scenario is located.

TABLE 4-27. 802.11 MAC Scenarios Included in EXata

Scenario Sub-directory	Description
dcf/adhoc-mode/directional-antenna	Shows the directional antenna functionality in ad hoc mode.
dcf/adhoc-mode/retry-limit	Illustrates the Transmit Limit functionality in ad hoc mode.
dcf/adhoc-mode/rts-cts	Illustrates the RTS-CTS procedure in ad hoc mode.
dcf/infrastructure/active-scanning	Shows the active scanning procedure.
dcf/infrastructure/directional-antenna	Shows the directional antenna functionality in infrastructure mode.
dcf/infrastructure/mgmt-frames	Shows the use of Test management frames following the four way handshake (RTS/CTS/Frame/ACK) procedure.
dcf/infrastructure/retry-limit	Shows the Transmit Limit Functionality in infrastructure mode.
dcf/infrastructure/rts-cts	Illustrates the RTS-CTS procedure in infrastructure mode.
pcf/IPv4/dont-poll	Illustrates the functionality of the PCF procedure when poll type for stations is configured as DONT-POLL.
pcf/IPv4/not-pollable	Illustrates the functionality of the PCF procedure when poll type for stations is configured as NOT-POLLABLE.
pcf/IPv4/pc-deliver	Shows the functionality of a PC in DELIVER-ONY mode.
pcf/IPv4/pc-pc	Shows the functionality of WLAN for multiple subnets.
pcf/IPv4/pc-pc-beacon-offset	Shows the functionality of WLAN for overlapping PCs with a delay between their beacon start times (offset of start of CFPs).
pcf/IPv4/pc-poll	Shows the functionality of a PC in POLL-ONLY mode.
pcf/IPv4/pc-poll-deliver	Shows the functionality of a PC in POLL-AND-DELIVER mode.
pcf/IPv4/pc-poll-nosave	Shows the functionality of a PC with Poll Save feature disabled.
pcf/IPv6/dont-poll	Shows the functionality of PCF model when poll type for stations is configured as don't poll.
pcf/IPv6/not-pollable	Shows the functionality of PCF model when poll type for stations is configured as not pollable.
pcf/IPv6/pc-deliver	Shows the functionality of PC in Delivery only mode.
pcf/IPv6/pc-pc	Shows the functionality of WLAN for multiple subnets.
pcf/IPv6/pc-pc-beacon-offset	Shows the functionality of WLAN for overlapping PCs with a delay between their beacon start time (offset of start of CFPs).
pcf/IPv6/pc-poll	Shows the functionality of PC in Poll only mode.
pcf/IPv6/pc-poll-deliver	Shows the functionality of PC in Poll and Delivery mode.
pcf/IPv6/pc-poll-nosave	Shows the functionality of PC with Poll Save feature disabled.
power-saving/IPv4/adhoc-mode	Shows the 802.11 PS mode implementation in ad hoc mode.
power-saving/IPv4/multi-channel	Shows the 802.11 PS mode model implementation in multichannel mode.

TABLE 4-27. 802.11 MAC Scenarios Included in EXata

Scenario Sub-directory	Description
power-saving/IPv4/ps-mode	Shows the 802.11 PS Mode model implementation in Infrastructure mode
power-saving/IPv4/ps-nonps	Shows the 802.11 PS Mode implementation, when PS mode is enabled at some nodes and disabled at other nodes.
power-saving/IPv4/tw-bss	Shows the 802.11 PS Mode model implementation in Infrastructure mode, when two BSS are present.
power-saving/IPv6/adhoc-mode	Shows the 802.11 PS mode implementation in ad hoc mode.
power-saving/IPv6/multi-channel	Shows the 802.11 PS Mode Model implementation in Multichannel mode.
power-saving/IPv6/ps-mode	Shows the 802.11 PS Mode model implementation in Infrastructure mode.
power-saving/IPv6/ps-nonps	Shows the 802.11 PS Mode implementation, when PS mode is enabled at some nodes and disabled at other nodes.
power-saving/IPv6/tw-bss	Shows the 802.11 PS Mode model implementation in Infrastructure mode, when two BSS are present in Scenario.

4.1.8 References

1. IEEE Std 802.11 -1999. "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications." March 18, 1999.
2. IEEE Std 802.11a–1999. "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band." September 16, 1999.
3. IEEE Std 802.11b-1999, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Higher-Speed Physical Layer Extension in the 2.4 GHz Band." September 16, 1999.
4. Bob O'Hara, Al Pet rick. The IEEE 802.11 Handbook: A Designers Companion. United States Of America:Standards Information Network IEEE Press.

4.2 802.11e MAC Protocol

The EXata 802.11e MAC model is based on the following documents:

- IEEE P802.11e/D10.0.
- IEEE P802.11e/D13.0.

4.2.1 Description

The IEEE 802.11e MAC enhances the basic 802.11 MAC to provide quality-of-service support for audio and video streams. The 802.11e MAC defines a new Hybrid Coordination Function (HCF), which provides an Enhanced Distributed Channel Access (EDCA) method and an HCF Controlled Channel Access (HCCA) method.

4.2.1.1 EDCA

The contention-based channel access of HCF is also referred to as EDCA. A new concept, transmission opportunity (TXOP), is introduced in IEEE 802.11e. A TXOP is a time period when a station has the right to initiate transmissions onto the wireless medium. It is defined by a starting time and a maximum duration. A station cannot transmit a frame that extends beyond a TXOP. If a frame is too large to be transmitted in a TXOP, it must be fragmented into smaller frames. EDCA works with four Access Categories (ACs), which are virtual DCFs as shown in Figure 4-17, where each AC achieves a differentiated channel access. This differentiation is achieved through varying the amount of time; a station would sense the channel to be idle, and the length of the contention window for a backoff.

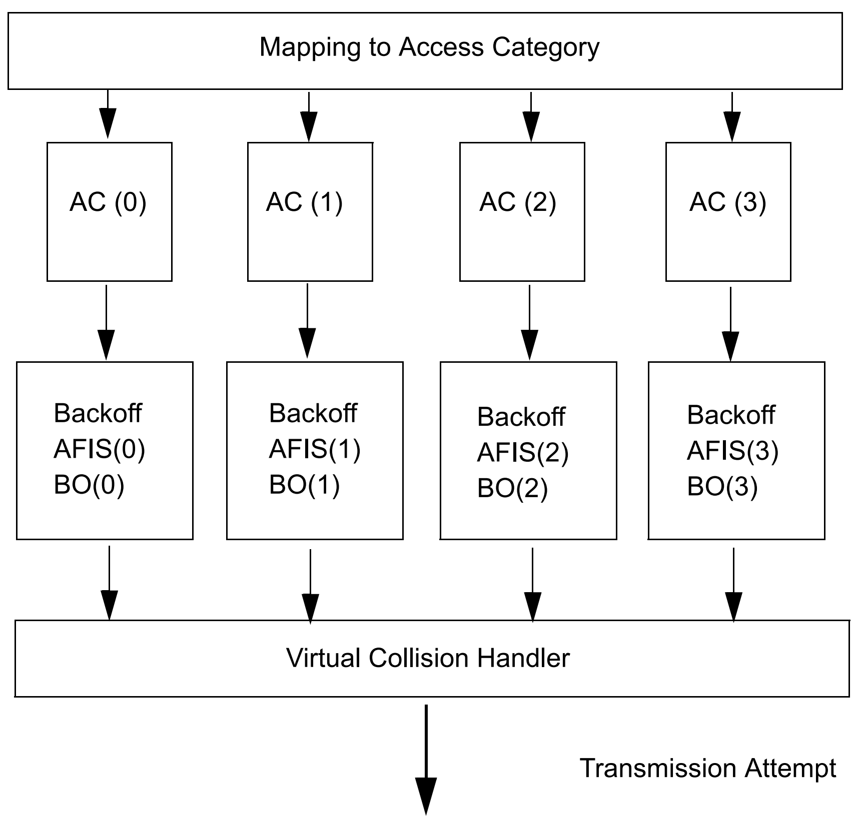


FIGURE 4-17. Enhanced Distributed Channel Access

Differentiated ACs are achieved by differentiating the Arbitration Inter-Frame Space (AIFS), the initial window size and the maximum window size. That is, for AC i (where i is 0, 1, 2, or 3),the initial backoff window size is CWmin[i], the maximum backoff window size is CWmax[i], and the arbitration inter-frame space is AIFS[i]. For 0 ≤ i ≤ j ≤ 3, we have CWmin[i] ≥ CWmin[j] and CWmax[i] ≥ CWmax[j], and AIFS[i] ≥ AIFS[j] and at least one of the above inequalities must be “not equal to”. In other words, the EDCA employs AIFS[i], CWmin[i], and CWmax[i] (all for i = 0,...,3) instead of DIFS, min CW and max CW, respectively. If one AC has a smaller AIFS or min CW, the traffic of AC has a better chance to access the wireless medium earlier, thus providing the QoS effect.

Traffic precedence values in EXata are mapped to access categories in EDCA as shown in Table 4-28.

TABLE 4-28. Mapping between Application Traffic Prudence and Access Categories

Precedence	Access Category
0	Packets are queued in AC[0]
1 and 2	Packets are queued in AC[1]
3, 4 and 5	Packets are queued in AC[2]
6 and 7	Packets are queued in AC[3]

4.2.1.2 HCCA

The contention-free channel access of HCF is also referred to as HCCA. HCCA allows for the reservation of TXOPs with the HC. A non-AP QSTA based on its requirements requests the HC for TXOPs - both for its own transmissions as well as transmissions from the QAP to itself. The request is initiated by the Station Management Entity (SME) of the non-AP QSTA. The HC, which is collocated at the QAP, either accepts or rejects the request based on an admission control policy. If the request is accepted, the HC schedules TXOPs for both the QAP and the non-AP QSTA.

For transmissions from the non-AP QSTA, the HC polls the non-AP QSTA based on the parameters supplied by the non-AP QSTA at the time of its request. For transmissions to the non-AP QSTA, the QAP directly obtains TXOPs from the collocated HC and delivers the queued frames to the non-AP QSTA, again based on the parameters supplied by the non-AP QSTA. This mechanism may be used for applications such as voice and video, which may need periodic service from the HC.

Admission Control and Scheduling of HCCA

In EXata 802.11e MAC model traffic specification includes user priority that will generate four traffic streams as per TSID (TS Identification). The QSTA initiates ADDTS request only if the priority of the data is between 4 to 7. The TSID will be generated by adding eight to User priority. HC will always accept the ADDTS request. HC will poll QSTA based on the priority of the traffic stream.

Traffic precedence values in EXata are mapped to access categories in HCCA as shown in Table 4-28.

4.2.2 Features and Assumptions

This section describes the implemented features, omitted features, assumptions and limitations of the 802.11e MAC model.

4.2.2.1 Implemented Features

- Contention based channel access of HCF (EDCA), QAP and QSTA.
- QBSS (both for infrastructure mode and ad hoc mode QIBSS).
- QoS extension to control and management.

- Coexistence of BSS/IBSS and QBSS/QIBSS in the same scenario.
- Coexistence of QSTAs and nQSTAs in the same QBSS/QIBSS.
- Priority parameters.
- HCF controlled channel access procedure(HCCA).
- TXOP structuring and TS generation.
- Basic Admission control, where HC will either accept or reject the request.

4.2.2.2 Omitted Features

- Block Acknowledgment (Block Ack).
- DLS (Direct Link Protocol Service).
- Support to higher-layer timer synchronization.

4.2.3 Command Line Configuration

To specify 802.11e MAC as the MAC protocol, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]  MAC-PROTOCOL        MAC-DOT11e
```

This scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

Note: The EXata 802.11e MAC model is based on the 802.11 MAC model. In order to use 802.11e MAC in a scenario, several 802.11 MAC parameters need to be configured as well. The 802.11 MAC parameters used by 802.11e MAC are listed in separate tables.

4.2.3.1 General Configuration

Table 4-30 shows the general 802.11e MAC configuration parameters. Table 4-30 shows the general 802.11 MAC configuration parameters used by the 802.11e MAC model.

TABLE 4-29. 802.11e MAC General Parameters

Parameter	Value	Description
`MAC-DOT11e-HCCA` *Optional* *Scope:* All	List: • `YES` • `NO` *Default:* `NO`	This parameter enables HCCA at a node/interface. **Note:** When the default value is set to `NO`, only EDCA will be used.

TABLE 4-30. 802.11 MAC General Parameters Used by 802.11e MAC

Parameter	Value	Description
`MAC-DOT11-SHORT-PACKET-TRANSMIT-LIMIT` *Optional* *Scope:* All	Integer *Range:* > 0 *Default:* 7	Specifies the maximum number of times a short packet (CTS/ACK) will be re-transmitted if no response is received during previous attempts.

TABLE 4-30. 802.11 MAC General Parameters Used by 802.11e MAC

Parameter	Value	Description
MAC-DOT11-LONG-PACKET-TRANSMIT-LIMIT *Optional* *Scope:* All	Integer *Range:* > *0* *Default:* 4	Specifies the maximum number of times a long packet (data) will be re-transmitted if no acknowledgement is received during previous attempts.
MAC-DOT11-RTS-THRESHOLD *Optional* *Scope:* All	Integer *Range:* ≥ *0* *Default:* 0 *Unit:* bytes	Specifies whether RTS/CTS is used based on data packet size. If data packet size is greater than *MAC-DOT11-RTS-THRESHOLD*, then RTS/CTS is used. Zero means always used RTS/CTS. Broadcast packets never use RTS/CTS.
MAC-DOT11-STOP-RECEIVING-AFTER-HEADER-MODE *Optional* *Scope:* All	List • YES • NO *Default:* NO	Specifies whether the node should stop receiving the packet after receiving the header if the packet is not addressed to the node.
MAC-DOT11-ASSOCIATION *Optional* *Scope:* All	List: • DYNAMIC • NONE *Default:* NONE	This parameter configures the mode of association with QAP/AP. Currently it supports two modes. If this parameter is set to DYNAMIC, then QSTA needs to be dynamically associated will QAP. This will set up a QIBSS (QoS enabled Infrastructure mode). If this parameter is set to NONE, then QSTA will work in Ad-Hoc mode. This will help to set up an ad hoc mode QoS enabled scenario.
MAC-DOT11-DIRECTIONAL-ANTENNA-MODE *Optional* *Scope:* All	List • YES • NO *Default:* NO	Specifies whether the radio will use a directional antenna for transmission and reception. YES : The radio will use a directional antenna. The following directional antenna mode parameters are also applicable: • MAC-DOT11-DIRECTION-CACHE-EXPIRATION-TIME • MAC-DOT11-DIRECTIONAL-NAV-AOA-DELTA-ANGLE • MAC-DOT11-DIRECTIONAL-SHORT-PACKET-TRANSMIT-LIMIT NO : The radio will not use a directional antenna.
MAC-DOT11-DIRECTION-CACHE-EXPIRATION-TIME *Optional* *Scope:* All	Time *Range:* ≥ *0S*	Specifies the time period for which the radio keeps track of the last known direction of the receiver (for the directional antenna mode). **Note:** This parameter must be specified if MAC-DOT11-DIRECTIONAL-ANTENNA-MODE is set to YES.

TABLE 4-30. 802.11 MAC General Parameters Used by 802.11e MAC

Parameter	Value	Description
MAC-DOT11-DIRECTIONAL-NAV-AOA-DELTA-ANGLE *Optional* *Scope:* All	Real *Unit:* degrees	Indicates the space that is NAV'ed when the radio overhears frames sent to neighboring nodes. **Note:** This parameter must be specified if MAC-DOT11-DIRECTIONAL-ANTENNA-MODE is set to YES.
MAC-DOT11-DIRECTIONAL-SHORT-PACKET-TRANSMIT-LIMIT *Optional* *Scope:* All	Integer *Range:* > 0 *Default:* 8	Specifies the number of times the radio re-tries to transmit control frames directionally before transmitting it using omni-directional antenna mode. **Note:** This parameter is applicable only if MAC-DOT11-DIRECTIONAL-ANTENNA-MODE is set to YES. **Note:** The default value is calculated using relation MAC-DOT11-DIRECTIONAL-SHORT-PACKET-TRANSMIT-LIMIT = MAC-DOT11-SHORT-PACKET-TRANSMIT-LIMIT + 1.
MAC-LAYER-STATISTICS *Optional* *Scope:* All	List: • YES • NO *Default:* NO	Indicates whether statistics are collected for MAC protocols, including 802.11 MAC.

4.2.3.2 Infrastructure Mode Configuration

Table 4-31 shows the 802.11e MAC infrastructure mode parameters. Table 4-32 shows the 802.11 MAC infrastructure mode parameters used by 802.11e MAC.

TABLE 4-31. 802.11e MAC Infrastructure Mode Parameters

Parameter	Value	Description
MAC-DOT11e-HC *Optional* *Scope:* All	List: • YES • NO *Default:* NO	This parameter configures a node/interface as HC. This parameter is only valid for an AP.
MAC-DOT11e-CAP-LIMIT *Optional* *Scope:* All	Real *Range:* (see note) *Default:* 50 *Unit:* TUs (see note)	This parameter specifies the maximum duration of CAP. HC cannot start CAP for more then this duration in a beacon period. **Note:** MAC-DOT11e-CAP-LIMIT should be greater than zero and less than MAC-DOT11-BEACON-INTERVAL (see Section 4.1). **Note:** A Time Unit (TU) is 1024 microseconds.

.

TABLE 4-32. 802.11 MAC Infrastructure Mode Parameters Used by 802.11e MAC

Parameter	Value	Description
`MAC-DOT11-SSID` *Optional* *Scope:* All	String *Default:* `TEST1`	Specifies the SSID of the station or access point. **Note:** For a station to associate with an access point, both the station and the access point should have this parameter set to the same value.
`MAC-DOT11-AP` *Optional* *Scope:* All	List • `YES` • `NO` *Default:* `NO`	Specifies whether the node is an access point (AP) or a station (STA). `YES` : The node is an AP. `NO` : The node is an STA.
`MAC-DOT11-BEACON-START-TIME` *Optional* *Scope:* All	Integer *Range: (see note)* *Unit:* TU	Specifies the beacon start time. If this parameter is not specified, the beacon start time is chosen randomly. **Note:** The value of this parameter should be between 0 and `MAC-DOT11-BEACON-INTERVAL` (both inclusive).
`MAC-DOT11-BEACON-INTERVAL` *Optional* *Scope:* All	Integer *Range:* `[0, 32767]` *Default:* `200` *Unit:* TU	Specifies the beacon interval.
`MAC-DOT11-RELAY-FRAMES` *Optional* *Scope:* All	List • `YES` • `NO` *Default:* `YES`	Specifies whether the AP relays frames to wireless nodes outside the BSS.
`MAC-DOT11-STA-CHANNEL` *Optional* *Scope:* All	Integer *Range:* ≥ 0	Specifies the index of the starting channel that the STA listens to for a dynamic association.
`MAC-DOT11-SCAN-TYPE` *Optional* *Scope:* All	List • `DISABLED` • `ACTIVE` • `PASSIVE` *Default:* `DISABLED`	Specifies the scanning method used by the STA when it is in dynamic association mode to discover an AP to associate with. `DISABLED` : No channel scanning. `ACTIVE` : Active probing of a channel to find an AP. `PASSIVE` : No probing. STA passively listens to channels for beacons.

4.2.4 GUI Configuration

This section describes how to configure 802.11 MAC in the GUI. Section 4.2.4.1 describes how to configure the general 802.11 MAC parameters. Section 4.2.4.2 describes the ad hoc mode configuration. Section 4.2.4.2 describes the infrastructure mode configuration. Section 4.2.4.3 describes how to enable statistics collection in the GUI.

Note: The default 802.11 MAC configuration is for ad hoc mode with both the power saving mode and the PCF procedure disabled.

4.2.4.1 General Configuration

To configure the general 802.11 MAC parameters, perform the following steps:

1. Go to one of the following locations:

- To set properties at the subnet level, go to **Wireless Subnet Properties Editor > MAC Layer**.
- To set properties at the interface level, go to one of the following locations:
  - **Interface Properties Editor > Interfaces > Interface # > MAC Layer**.
  - **Default Device Properties Editor > Interfaces > Interface # > MAC Layer**.

In this section, we show how to configure the general 802.11e MAC parameters in the Wireless Subnet Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **MAC Protocol** to *802.11e* and set the dependent parameters listed in Table 4-33.

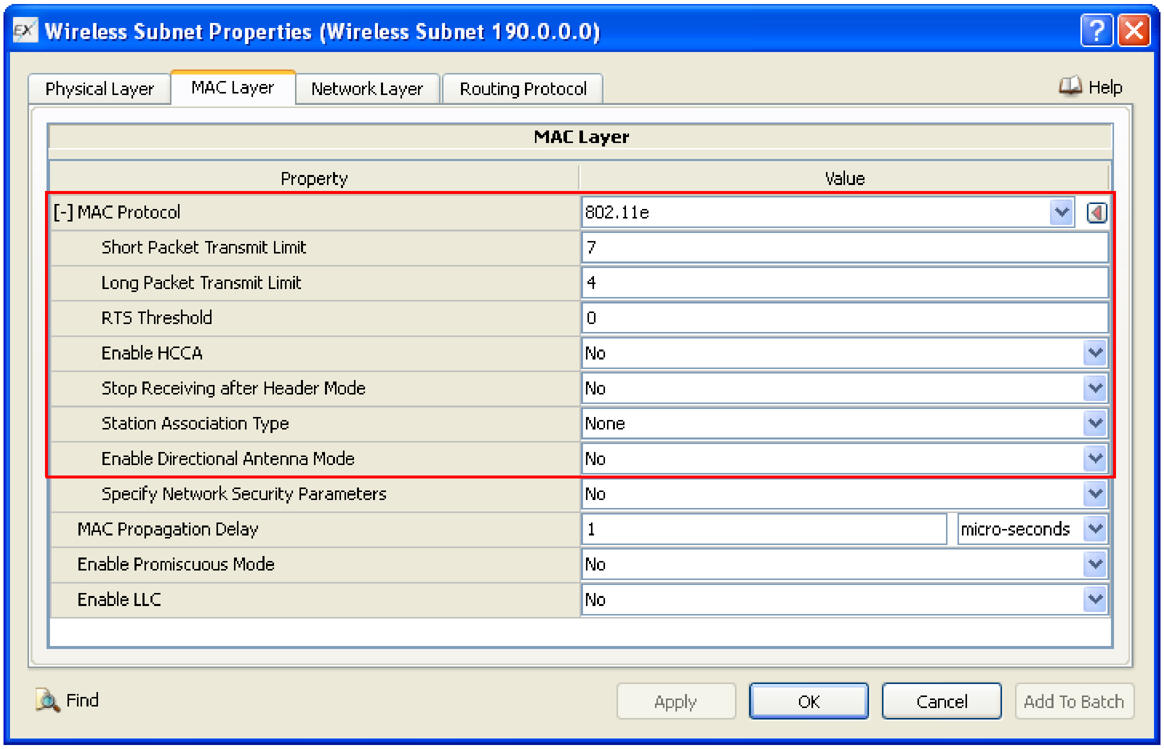


FIGURE 4-18. Configuring 802.11 MAC General Parameters

TABLE 4-33. Command Line Equivalent of 802.11e MAC General Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Short Packet Transmit Limit	Subnet, Interface	`MAC-DOT11-SHORT-PACKET-TRANSMIT-LIMIT`
Long Packet Transmit Limit	Subnet, Interface	`MAC-DOT11-SHORT-PACKET-TRANSMIT-LIMIT`
RTS Threshold	Subnet, Interface	`MAC-DOT11-RTS-THRESHOLD`
Enable HCCA	Subnet, Interface	`MAC-DOT11e-HCCA`
Stop Receiving after Header Mode	Subnet, Interface	`MAC-DOT11-STOP-RECEIVING-AFTER-HEADER-MODE`
Station Association Type	Subnet, Interface	`MAC-DOT11-ASSOCIATION`
Enable Directional Antenna Mode	Subnet, Interface	`MAC-DOT11-DIRECTIONAL-ANTENNA-MODE`

Setting Parameters

- To enable HCCA, set **Enable HCCA** to *Yes; o*therwise, set **Enable HCCA** to *No* to use only EDCA.
- To enable the infrastructure mode, set **Station Association Type** to *Dynamic* and configure the infrastructure mode parameters, as described in Section 4.2.4.2.

- To enable directional antenna mode, set **Directional Antenna Mode** to *Yes*; otherwise, set **Directional Antenna Mode** to *No*.

3. If **Directional Antenna Mode** is set to *Yes*, set the dependent parameters listed in Table 4-34.

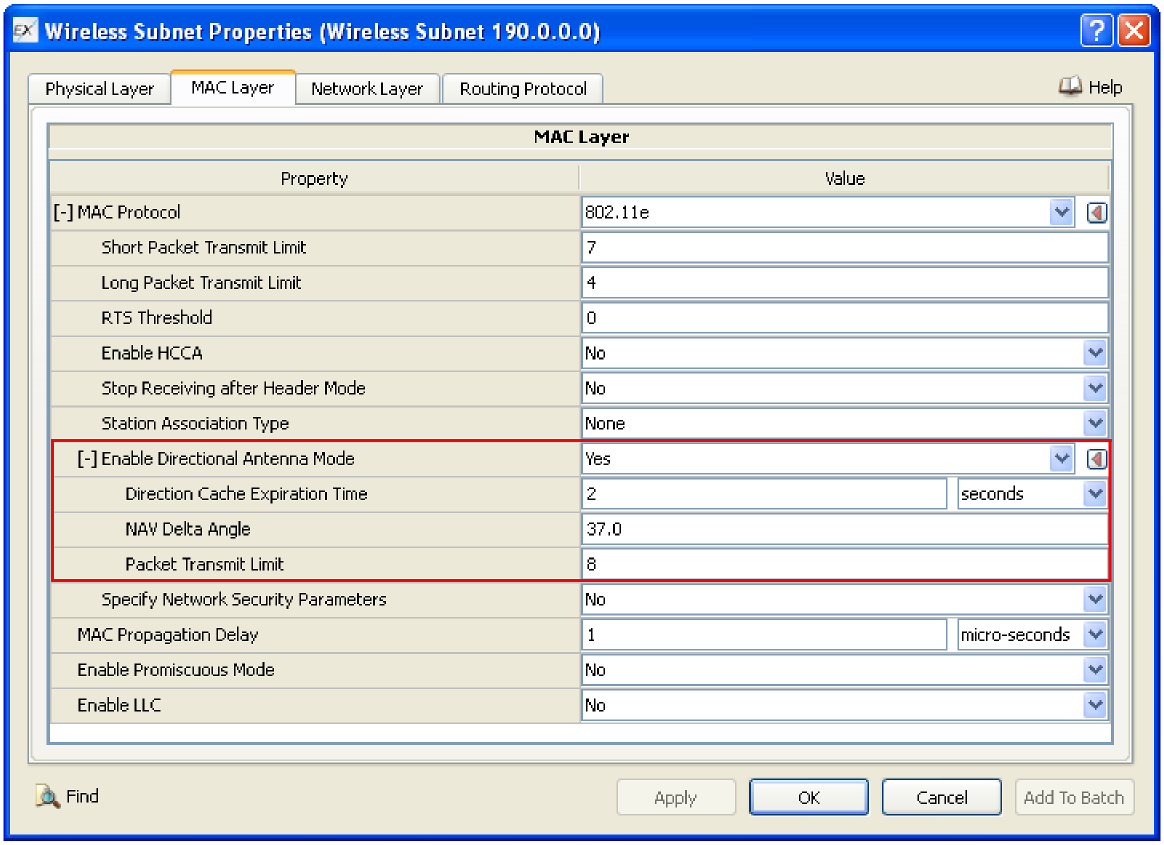


FIGURE 4-19. Configuring Directional Antenna Mode

TABLE 4-34. Command Line Equivalent of Directional Antenna Mode Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Direction Cache Expiration Time	Subnet, Interface	`MAC-DOT11-DIRECTION-CACHE-EXPIRATION-TIME`
NAV Delta Angle	Subnet, Interface	`MAC-DOT11-DIRECTIONAL-NAV-AOA-DELTA-ANGLE`
Packet Transmit Limit	Subnet, Interface	`MAC-DOT11-DIRECTIONAL-SHORT-PACKET-TRANSMIT-LIMIT`

4.2.4.2 Infrastructure Mode Configuration

The infrastructure mode can be selected at both the interface and subnet levels. The access point can be configured only at the interface level.

In this section, we show how to configure the ad hoc mode parameters in the Interface Properties Editor. Applicable parameters can be set in the other properties editors in a similar way.

To configure the 802.11e MAC infrastructure mode parameters, perform the following steps:

1. Set the general 802.11e MAC parameters, as described in Section 4.2.4.1.
2. Set **MAC Protocol** *[= 802.11e]* **> Station Association Type** to *Dynamic* and set the dependent parameters listed in Table 4-35.

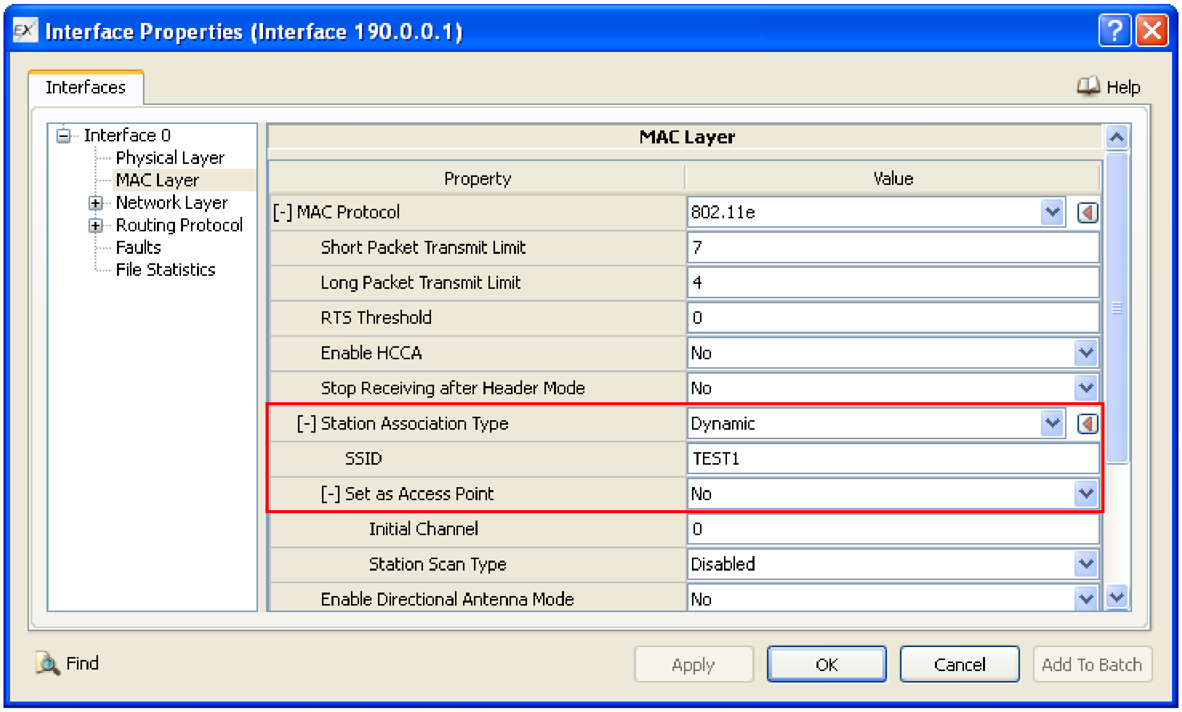


FIGURE 4-20. Configuring Infrastructure Mode parameters

TABLE 4-35. Command Line Equivalent of Infrastructure Mode Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
SSID	Subnet, Interface	`MAC-DOT11-SSID`
Set as Access Point	Subnet, Interface	`MAC-DOT11-AP`

Setting Parameters

- To configure the node as a station, set **Set as Access Point** to *No*. To configure the node as an access point, set **Set as Access Point** to *Yes*. Configure the parameters for access points and stations as described below.
- For a station to associate with an access point, **SSID** should be set to the same value for both the station and the access point.

Infrastructure Mode Configuration for an Access Point

To configure a node as an access point, perform the following steps:

1. Set **MAC Protocol** *[= 802.11e]* **> Station Association Type** *[= Dynamic]* **> Set as Access Point** to *Yes* and set the dependent parameters listed in Table 4-36.

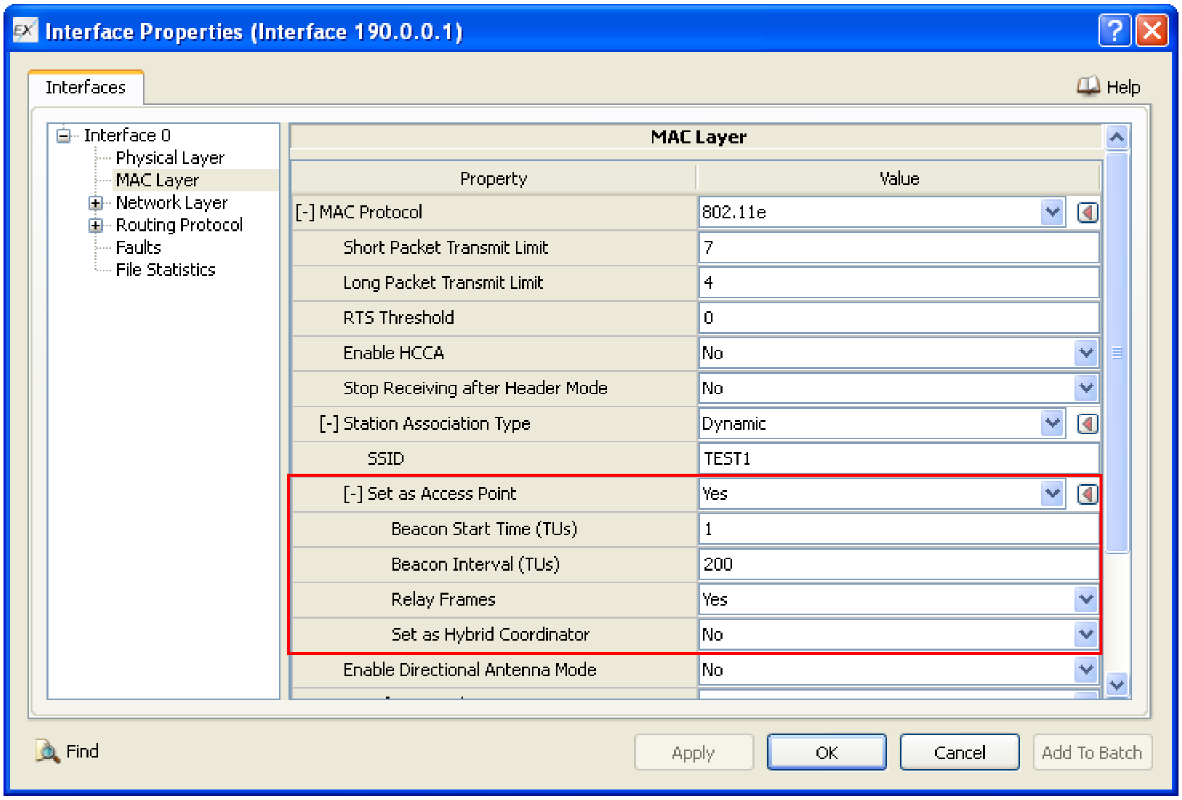


FIGURE 4-21. Configuring Access Point Parameters

TABLE 4-36. Command Line Equivalent of Access Point Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Beacon Start Time	Subnet, Interface	`MAC-DOT11-BEACON-START-TIME`
Beacon Interval	Subnet, Interface	`MAC-DOT11-BEACON-INTERVAL`
Relay Frames	Subnet, Interface	`MAC-DOT11-RELAY-FRAMES`
Set as Hybrid Coordinator	Interface	`MAC-DOT11e-HC`

Setting Parameters

- Set **Set as Hybrid Coordinator** to *Yes* to configure the node as a Hybrid Coordinator; otherwise, set **Set as Hybrid Coordinator** to *No.*

2. If **Set as Hybrid Coordinator** is set to *Yes*, set the dependent parameters listed in Table 4-37.

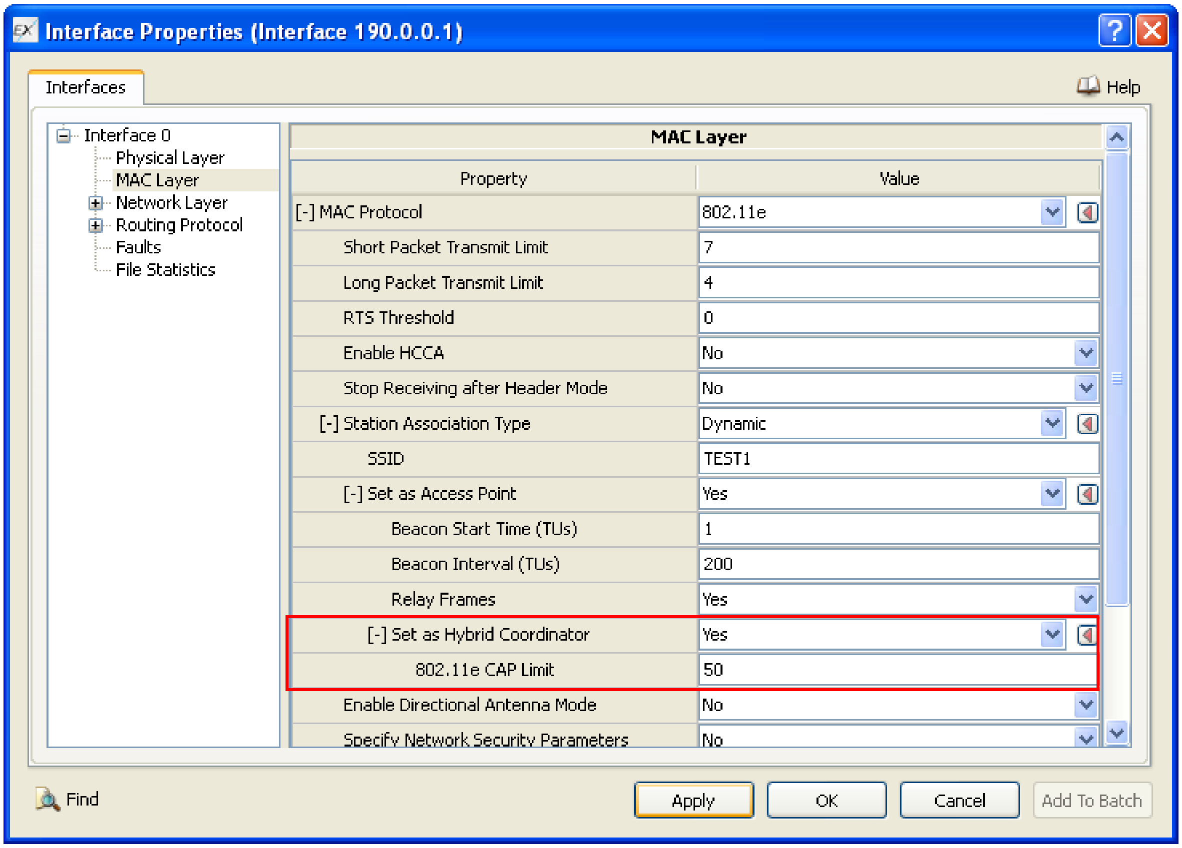


FIGURE 4-22. Configuring Hybrid Coordinator

TABLE 4-37. Command Line Equivalent of Hybrid Coordinator Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
802.11e CAP Limit	Interface	`MAC-DOT11e-CAP-LIMIT`

Infrastructure Mode Configuration for a Station

To configure a node as a station, perform the following steps:

1. Set **MAC Protocol** *[= 802.11e]* **> Station Association Type** *[= Dynamic]* **> Set as Access Point** to *No* and set the dependent parameters listed in Table 4-38.

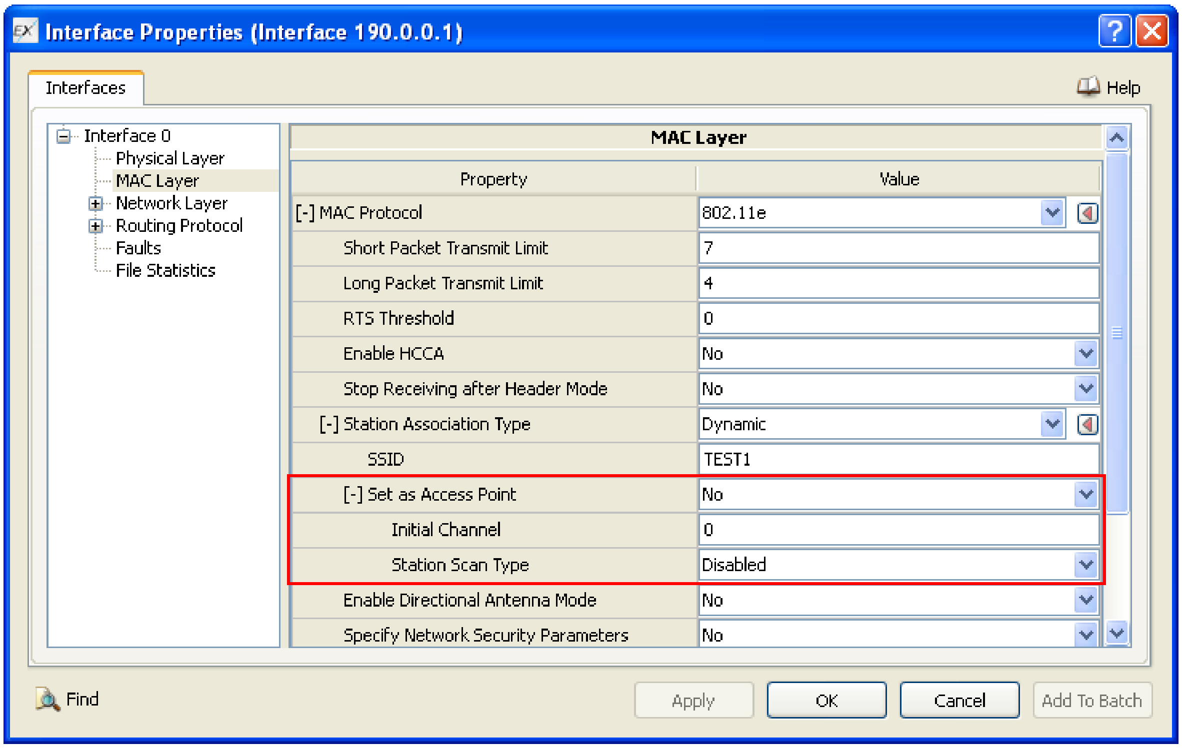


FIGURE 4-23. Setting Station Parameters for Infrastructure Mode.

TABLE 4-38. Command Line Equivalent of Infrastructure Mode Parameters for a Station

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Initial Channel	Subnet, Interface	`MAC-DOT11-STA-CHANNEL`
Station Scan Type	Subnet, Interface	`MAC-DOT11-SCAN-TYPE`

4.2.4.3 Configuring Statistics Parameters

Statistics for 802.11e MAC can be collected at the global, node, subnet, and interface levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for MAC protocols including 802.11e MAC, check the box labeled **MAC** in the appropriate properties editor.

TABLE 4-39. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
MAC	Global, Node, Subnet, Interface	`MAC-LAYER-STATISTICS`

4.2.5 Statistics

Table 4-40 shows the 802.11e MAC statistics that are output to the statistics (.stat) file at the end of simulation.

Note: 802.11e MAC also enables the 802.11 MAC statistics. See Section 4.1.5 for a description of 802.11 MAC statistics.

TABLE 4-40. 802.11e MAC Statistics

Statistic	Description
General 802.11e MAC Statistics	
AC[0] Total Frame Queued	Total Background packet queued.
AC[0] Total Frame de-Queued	Total Background packet de-queued.
AC[1] Total Frame Queued	Total Best effort packet queued.
AC[1] Total Frame de-Queued	Total Best effort packet de-queued.
AC[2] Total Frame Queued	Total Video traffic packet queued.
AC[2] Total Frame de-Queued	Total Video packet de-queued.
AC[3] Total Frame Queued	Total Voice traffic queued.
AC[3] Total Frame de-Queued	Total Voice traffic de-queued.
QoS Data Frame send	Total QoS data frames sent.
Non-QoS Data Frame send	Total non-QoS data frames sent.
QoS Data Frame received	Total QoS data frames received.
Non-QoS Data Frame received	Total non-QoS data frames received.
HCCA Statistics (see note)	
HCCA: Polls transmitted	Total polls transmitted.
HCCA: Polls received	Total polls received.
HCCA: Data packets transmitted	Total data packets transmitted.
HCCA: Data packets transmitted	Total data packets transmitted.
HCCA: Null Data received	Total Null data received.

Note: HCCA statistics are printed only when it is enabled in 802.11e MAC protocol.

4.2.6 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the 802.11e MAC protocol. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/dot11e. Table 4-41 lists the sub-directory where each scenario is located.

TABLE 4-41. 802.11e MAC Scenarios Included in EXata

Scenario Sub-directory	Description
dot11e-ad-hoc-mode	Shows how Dot11e (MAC 802.11e) protocol operates in ad hoc network.
dot11e-multichannel	Shows how Dot11e (MAC 802.11e) protocol operates in multichannel and QIBSS mode.
dot11e-qibss	Shows how Dot11e (MAC 802.11e) protocol operates in Infrastructure mode.
dot11e-qibss-ibss	Shows how in Dot11e (MAC 802.11e) & Dot11 environment, QSTA sends non QoS packet, when associated with nQSTA and nQSTA send non QoS Packet even when associated with QAP.
dot11e-qsta-nqsta	Shows how in Dot11e (MAC 802.11e) & Dot11 environment QSTA sends non QoS packet to nQSTA, when required/asked to send in ad hoc mode.
dot11e-traffic-load	Shows how Dot11e (MAC 802.11e) protocol operates in various priority traffics in QIBSS mode.
hcca\hcca-admission-control	Shows basic Admission Control at HC.
hcca\hcca-multicast-data	Shows how EXata dot11e model handles multicast data.
hcca\hcca-priority-data	Shows how Dot11e (MAC 802.11e) handles priority data.
hcca\hcca-qbss-qbss	Shows Dot11e model functionality, when two QBSS are present in Scenario.
hcca\hcca-qsta-nqsta	Shows how QSTA sends non QoS packet to nQSTA.

4.2.7 References

1. IEEE P802.11e/D10.0, "Part 11: Wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications: Amendment 7: Medium Access Control (MAC) Quality of Service (QoS) Enhancements." September 2004.
2. IEEE P802.11e/D13.0, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Amendment: Medium Access Control (MAC) Quality of Service (QoS) Enhancements." January 2005.
3. P. Garg, R. Doshi, R. Greene, M. Baker, M. Malek, and X. Cheng, "Using IEEE 802.11e MAC for QoS over Wireless." 22nd IEEE International Performance Computing and Communications Conference (IPCCC 2003). April 2003.

4.3 802.11n MAC Protocol

4.3.1 Description

The IEEE 802.11 HT STA provides physical layer (PHY) features that can support a throughput of 100 Mbps and greater, as measured at the MAC data Service Access Point (SAP). An HT STA is also a Quality of Service (QoS) STA. The HT features are available to HT STAs associated with an HT Access Point (AP) in a Basic Service Set (BSS). A subset of the HT features is available for use between two HT STAs that are members of the same Independent Basic Service Set (IBSS).

An HT STA implements the following MAC features:

- Frame aggregation
- Block Acknowledgment (Block-Ack)
- Power Save Multi-Poll (PSMP) operation
- Reverse Direction (RD) protocol
- Protection mechanisms supporting coexistence with non-HT STAs.

4.3.2 Features and Assumptions

This section describes the implemented features, omitted features, assumptions and limitations of the 802.11nPHY model.

4.3.2.1 Implemented Features

- AMSDU operation
- AMPDU operation
- Immediate Block-Ack
- Delayed Block-Ack
- Reduced Inter-Frame Space (RIFS)

4.3.2.2 Omitted Features

- Dual CTS protection
- Control Wrapper operation
- A-MPDU aggregation of group-addressed data frames
- Protected Block-Ack agreement
- Protection mechanisms
- Reverse Direction protocol
- HT-Mixed mode operation
- All security related features
- Antenna selection

4.3.2.3 Assumptions and Limitations

- Only in EDCA mode is supported.
- Only Green field mode is supported.
- Burst mode (RIFS) works only for packets with priority 3 and higher.
- Aggregation of packets during burst mode is not supported.

- When burst mode is enabled, AMSDU and AMPDU functionalities are turned off.
- Beacons are not used for ad-hoc mode. Capability information in ad-hoc mode is exchanged via a probe request/response mechanism.
- Power-save and HCCA modes are not supported.

4.3.3 Command Line Configuration

To enable the 802.11n MAC model, configure the MAC protocol to be 802.11e MAC (see Section 4.2) and the radio model to be 802.11n PHY (see Section 3.3).

Table 4-42 lists the 802.11n MAC parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 4-42. 802.11n MAC Parameters

Parameter	Value	Description
`MAC-DOT11N-ENABLE-DATA-BURSTING` *Optional* *Scope:* All	List • `YES` • `NO` *Default:* `NO`	Enables burst mode operation.
`MAC-DOT11N-AMSDU-ENABLE` *Optional* *Scope:* All	List • `YES` • `NO` *Default:* `NO`	Enables the formation of Aggregated MAC Service Data Units (AMSDUs). **Note:** This parameter is used only if `MAC-DOT11N-ENABLE-DATA-BURSTING` is set to `NO`.
`MAC-DOT11N-ENABLE-BIG-AMSDU` *Optional* *Scope:* All	List • `YES` • `NO` *Default:* `NO`	Specifies if the station can receive big (7 KB) AMSDUs. **Note:** This parameter is used only if `MAC-DOT11N-AMSDU-ENABLE` is set to `YES`.
`MAC-DOT11N-AMSDU-BUFFER-TIMER-INTERVAL` *Optional* *Scope:* All	Time *Range:* `> 0S` *Default:* `5MS`	Specifies the time for which the oldest packet in the AMSDU buffer will wait for more packets to be queued in the buffer before forming an AMSDU from the queued packets. **Note:** This parameter is used only if `MAC-DOT11N-AMSDU-ENABLE` is set to `YES`.
`MAC-DOT11N-AMPDU-ENABLE` *Optional* *Scope:* All	List • `YES` • `NO` *Default:* `NO`	Enables the formation of Aggregated MAC Protocol Data Unit (AMPDU). **Note:** This parameter is used only if `MAC-DOT11N-ENABLE-DATA-BURSTING` is set to `NO`.
`MAC-DOT11N-AMPDU-LENGTH-EXPONENT` *Optional* *Scope:* All	Integer *Range:* `[0, 3]` *Default:* `1`	Specifies the exponent used to calculate the maximum size of an AMPDU that a station can receive. The maximum length of an AMPDU is equal to $2^{(13 + \text{Maximum AMPDU Length Exponent})} - 1$ octets. **Note:** This parameter is used only if `MAC-DOT11N-AMPDU-ENABLE` is set to `YES`.

TABLE 4-42. 802.11n MAC Parameters (Continued)

Parameter	Value	Description
`MAC-DOT11N-ENABLE-DELAYED-BLOCK-ACK` *Optional* *Scope:* All	List • `YES` • `NO` *Default:* `NO`	Enables delayed block acknowledgement operation. **Note:** This parameter is used only if `MAC-DOT11N-ENABLE-DATA-BURSTING` is set to `YES`.
`MAC-DOT11N-BLOCK-ACK-POLICY-TIMEOUT` *Optional* *Scope:* All	Time *Range:* `> 0S` *Default:* `500MS`	Specifies the timeout value used in the Block-Ack policy. **Note:** This parameter is used only if `MAC-DOT11N-ENABLE-DATA-BURSTING` is set to `YES`.
`MAC-DOT11N-ENABLE-RIFS-MODE` *Optional* *Scope:* All	List • `YES` • `NO` *Default:* `NO`	Enables RIFS mode. **Note:** This parameter is used only if `MAC-DOT11N-ENABLE-DATA-BURSTING` is set to `YES`.
`MAC-DOT11N-REORDERING-BUFFER-TIMER-INTERVAL` *Optional* *Scope:* All	Time *Range:* `> 0S` *Default:* `100MS`	Specifies the timeout value for the input buffer which also acts as a reordering buffer. After this timeout, the next packet/packets in continuous sequence are dequeued from the input queue and processed.
`MAC-DOT11N-QUEUE-SIZE-PER-DESTINATION` *Optional* *Scope:* All	Integer *Range:* `> 0` *Default:* `80` *Unit:* packets	Specifies the output queue size per Receiver Address/Traffic Identifier (RA/TID).

4.3.4 GUI Configuration

To configure the 802.11n MAC parameters, perform the following steps:

1. Configure the radio model to be 802.11n Radio, as described in Section 3.3.4.
2. Go to one of the following locations:
   - To set properties for a specific wireless subnet, go to **Wireless Subnet Properties Editor > MAC Layer**.
   - To set properties for a specific interface of a node, go to one of the following locations:
     - **Default Device Properties Editor > Interfaces > Interface # > MAC Layer**.
     - **Interface Properties Editor > Interfaces > Interface # > MAC Layer**.

   In this section, we show how to configure antenna for a specific interface using the Wireless Subnet Properties Editor. Parameters can be set in the other properties editors in a similar way.
3. Set **MAC Protocol** to *802.11e* and configure the MAC 802.11e parameters as described in Section 4.2.4.

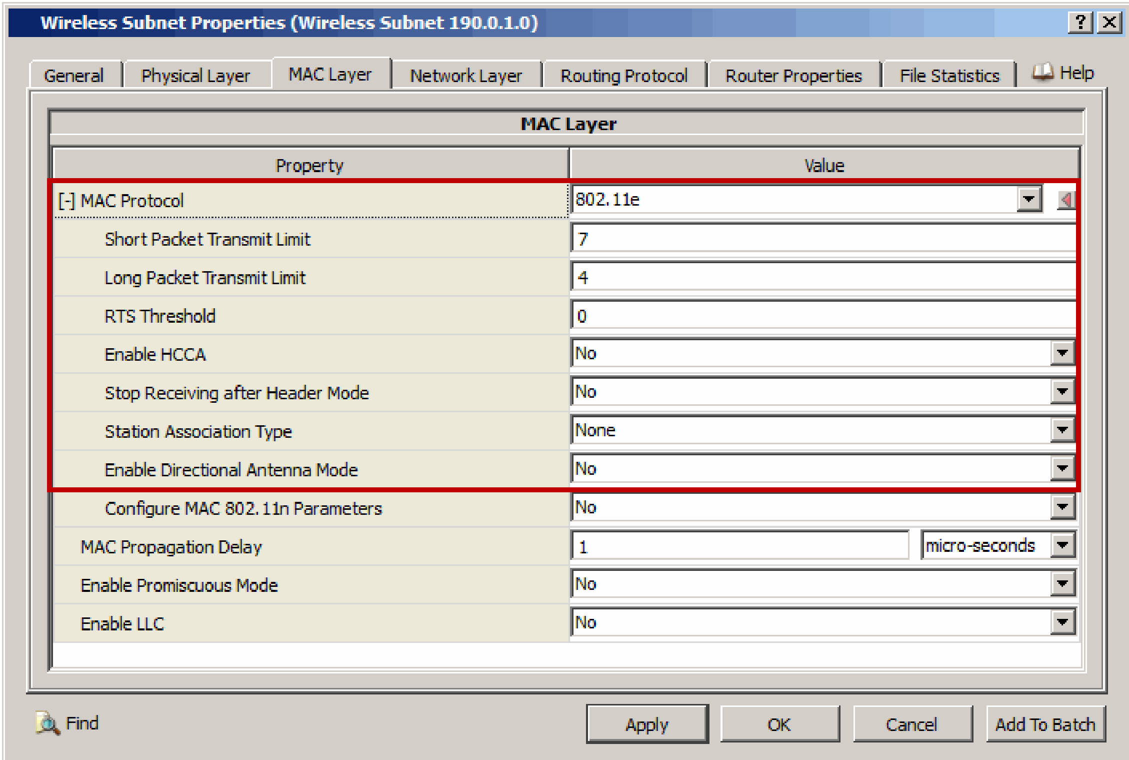


FIGURE 4-24. Configuring 802.11e MAC Parameters

4. Set **Configure MAC 802.11n Parameters** to *Yes* and set the dependent parameters listed in Table 4-43.

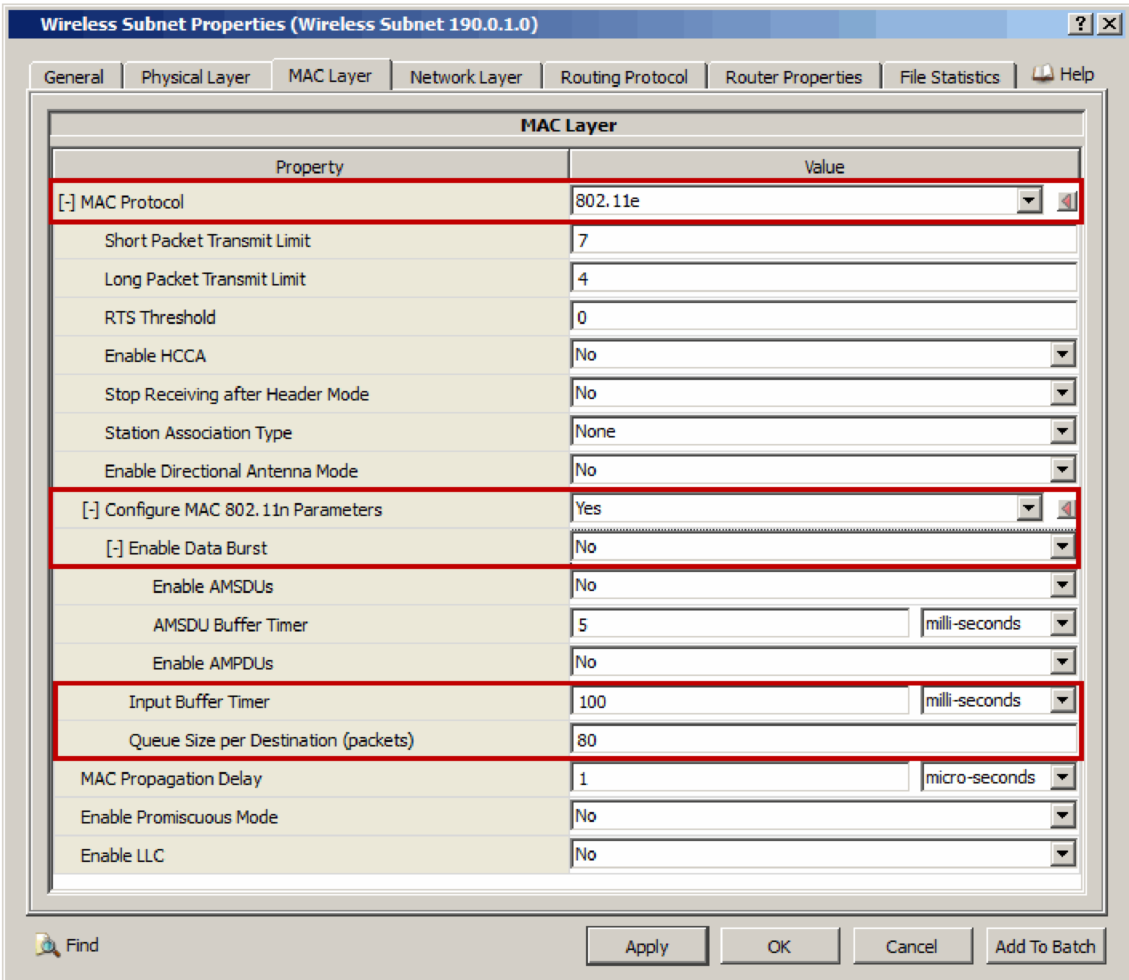


FIGURE 4-25. Setting 802.11n MAC Parameters

TABLE 4-43. Command Line Equivalent of 802.11n MAC Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Enable Data Burst	Node, Interface, Subnet	`MAC-DOT11N-ENABLE-DATA-BURSTING`
Input Buffer Timer	Node, Interface, Subnet	`MAC-DOT11N-REORDERING-BUFFER-TIMER-INTERVAL`
Queue Size per Destination (packets)	Node, Interface, Subnet	`MAC-DOT11N-QUEUE-SIZE-PER-DESTINATION`

5. If **Enable Data Burst** is set to *No*, then set the dependent parameters listed in Table 4-43.

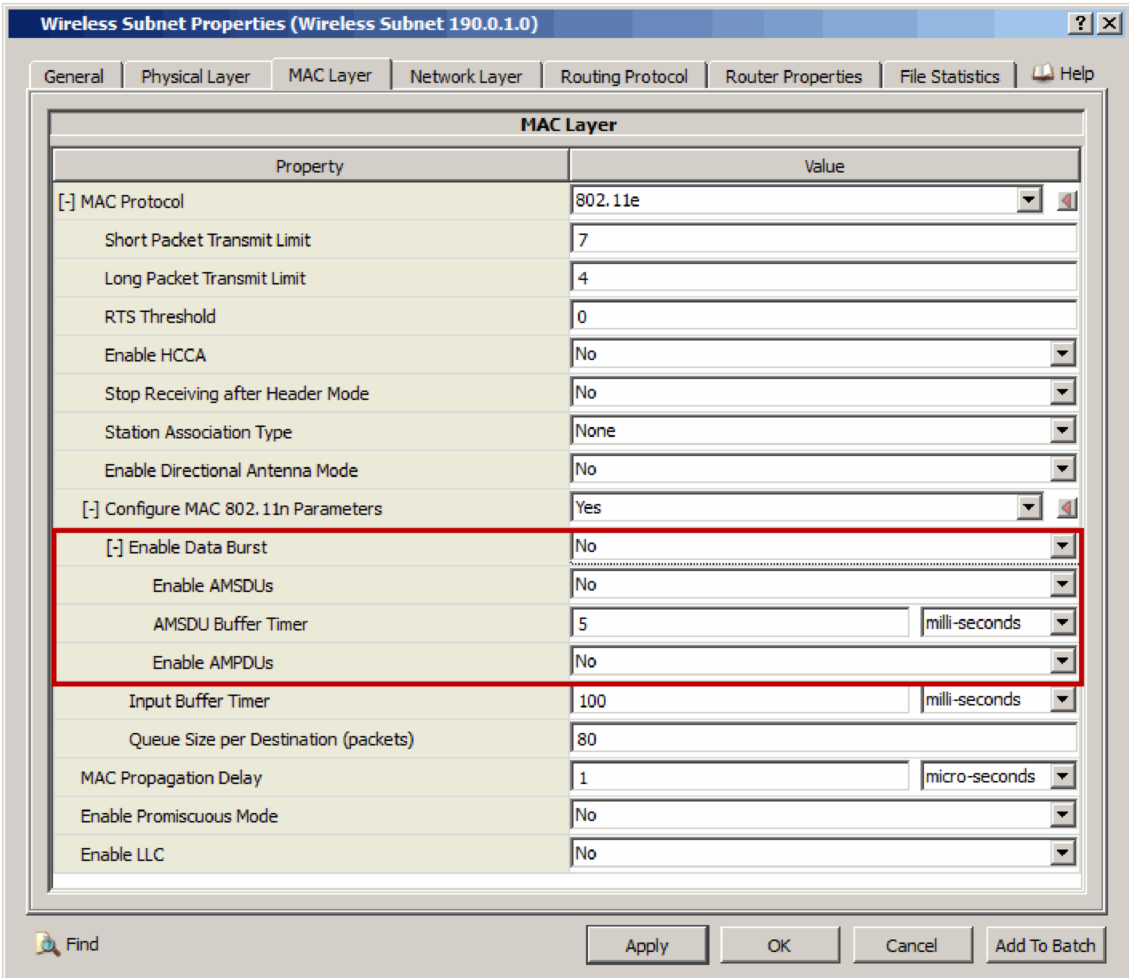


FIGURE 4-26. Configuring 802.11n Parameters when Burst Mode is Disabled

TABLE 4-44. Command Line Equivalent of 802.11n Parameters when Burst Mode is Disabled

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Enable AMSDUs	Node, Interface, Subnet	`MAC-DOT11N-AMSDU-ENABLE`
AMSDU Buffer Timer	Node, Interface, Subnet	`MAC-DOT11N-AMSDU-BUFFER-TIMER-INTERVAL`
Enable AMPDUs	Node, Interface, Subnet	`MAC-DOT11N-AMPDU-ENABLE`

6. If **Enable AMSDUs** is set to *Yes*, then set the dependent parameters listed in Table 4-43.

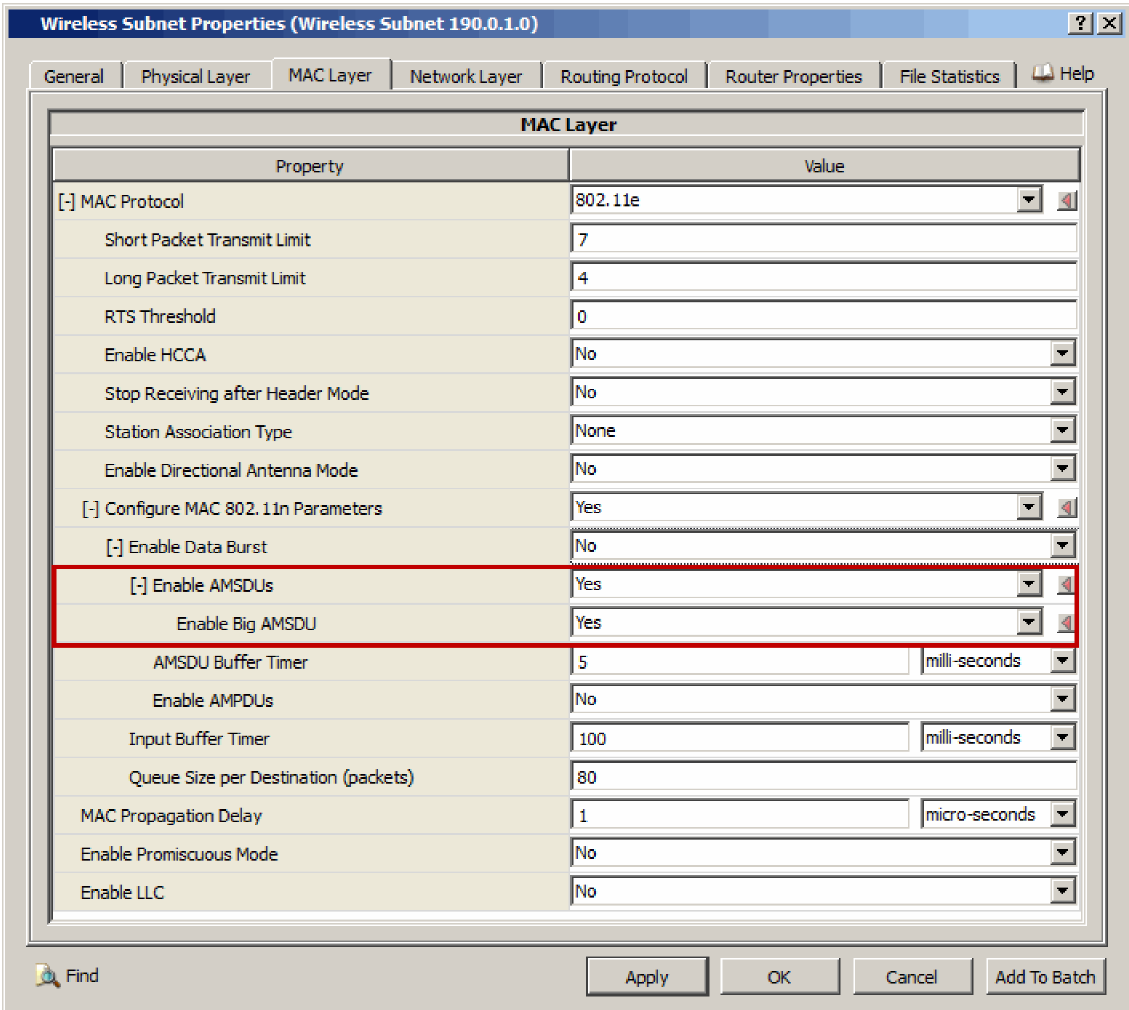


FIGURE 4-27. Configuring AMSDU Parameters

TABLE 4-45. Command Line Equivalent of AMSDU Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Enable Big AMSDU	Node, Interface, Subnet	`MAC-DOT11N-ENABLE-BIG-AMSDU`

7. If **Enable AMPDUs** is set to *Yes*, then set the dependent parameters listed in Table 4-43.

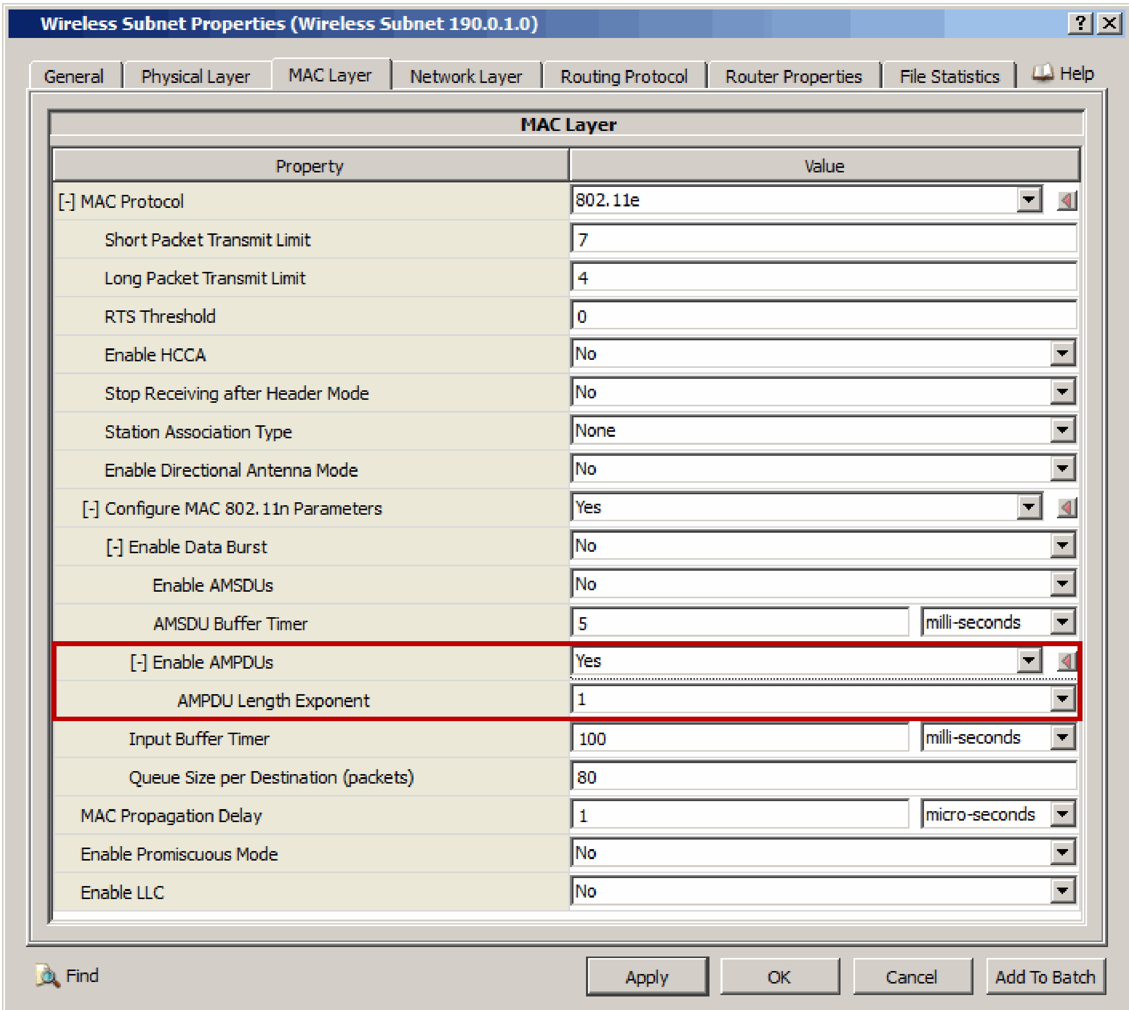


FIGURE 4-28. Configuring AMPDU Parameters

TABLE 4-46. Command Line Equivalent of AMSDU Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
AMPDU Length Exponent	Node, Interface, Subnet	`MAC-DOT11N-AMPDU-LENGTH-EXPONENT`

8. If **Enable Data Burst** is set to *Yes*, then set the dependent parameters listed in Table 4-43.

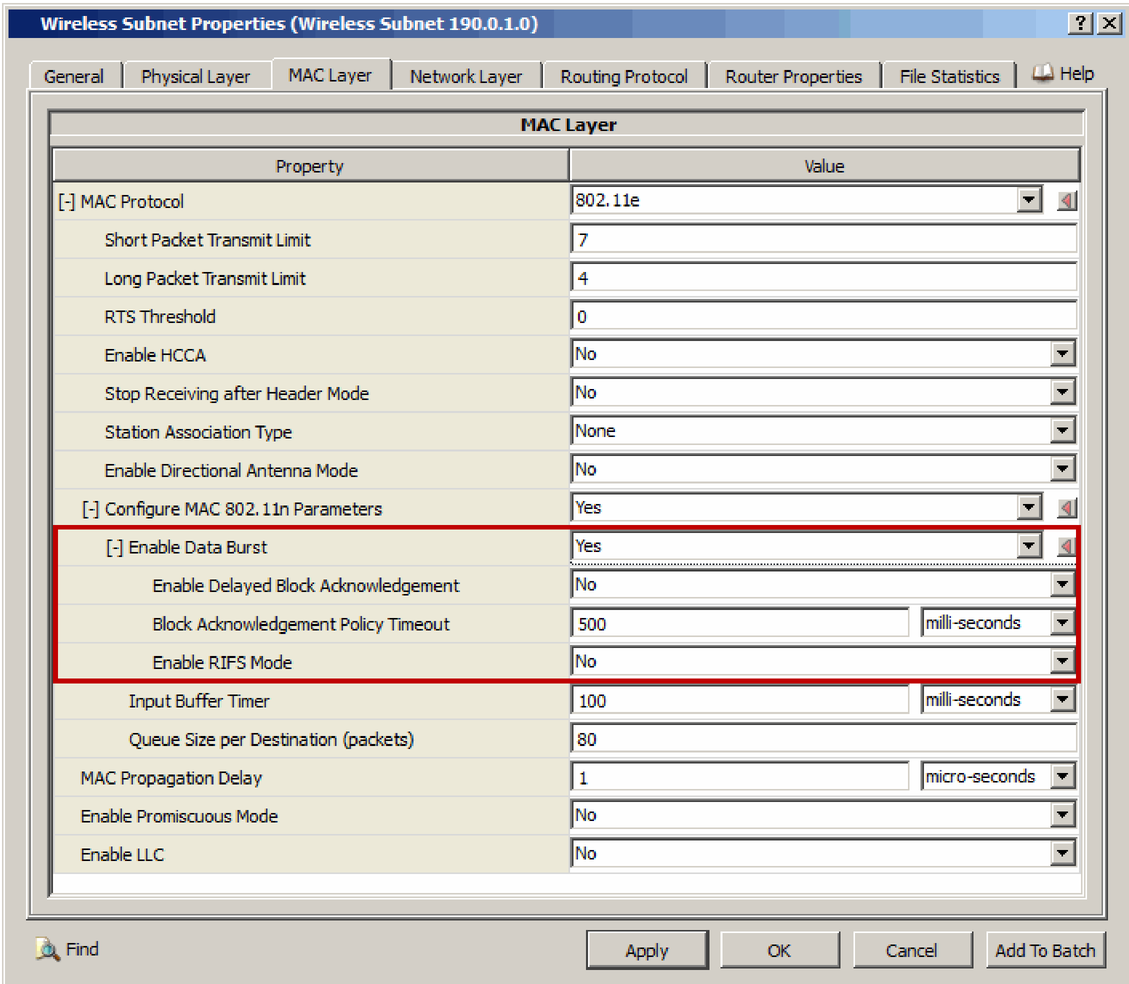


FIGURE 4-29. Configuring 802.11n Data Burst Mode Parameters

TABLE 4-47. Command Line Equivalent of 802.11n Data Burst Mode Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Enable Delayed Block Acknowledgement	Node, Interface, Subnet	`MAC-DOT11N-ENABLE-DELAYED-BLOCK-ACK`
Block Acknowledgement Policy Timeout	Node, Interface, Subnet	`MAC-DOT11N-BLOCK-ACK-POLICY-TIMEOUT`
Enable RIFS Mode	Node, Interface, Subnet	`MAC-DOT11N-ENABLE-RIFS-MODE`

4.3.5 Statistics

This section describes the 802.11n statistics that are output to the statistics (.stat) file at the end of simulation.

Generic Statistics

Table 4-48 lists the general statistics for the 802.11n MAC model.

TABLE 4-48. General Statistics for 802.11n MAC

Statistics	Description
Packets from network	Total number of packets from network
Unicast packets sent to channel	Total number of unicast packets sent to channel
Broadcast packets sent to channel	Total number of broadcast packets sent to channel
Unicast packets received clearly	Total number of unicast packets received clearly
Broadcast packets received clearly	Total number of broadcast packets received clearly
Unicasts sent	Total number of unicasts sent
Packets queued in AMSDU buffer	Total number of packets queued in AMSDU Buffer
Packets de-queued from AMSDU buffer as AMSDU	Total number of packets de-queued as AMSDU's from AMSDU buffer
Packets de-queued from AMSDU buffer as MSDU	Total number of packets de-queued as MSDU's from AMSDU buffer
Packets dropped from AMSDU buffer	Total number of packets dropped from AMSDU buffer
Packets queued in output buffer	Total number of packets queued in the output buffer
Packets de-queued from output buffer	Total number of packets de-queued from the output buffer
Packets dropped from output buffer	Total number of packets dropped from the output buffer
Packets queued in reordering buffer	Total number of packets queued in the reordering buffer
Packets de-queued from reordering buffer	Total number of packets de-queued from the reordering buffer
Packets discarded due to seq mismatch	Total number of packets discarded due to sequence number mismatch
Packets discarded due to invalid state	Total number of packets discarded due to invalid state
MSDUs combined to form AMSDUs	Total number of MSDUs combined to form AMSDUs
AMSDUs created	Total number of AMSDUs created
AMSDUs sent	Total number of AMSDUs sent
AMSDUs received	Total number of AMSDUs received
AMSDUs retried	Total number of AMSDUs retried
AMSDUs dropped	Total number of AMSDUs dropped
AMSDUs combined to form AMPDUs	Total number of AMSDUs combined to form AMPDUs
MSDUs combined to form AMPDUs	Total number of MPDUs combined to form AMPDUs
AMPDUs created	Total number of AMPDUs created
AMPDUs sent	Total number of AMPDUs sent
AMPDUs received	Total number of AMPDUs received
AMPDUs retried	Total number of AMPDUs retried
AMPDUs dropped	Total number of AMPDUs dropped

TABLE 4-48. General Statistics for 802.11n MAC (Continued)

Statistics	Description
Immediate block-ack request sent	Total number of Immediate Block Ack requests sent
Immediate block-ack request received	Total number of Immediate Block Ack requests received
Immediate block-ack request dropped	Total number of Immediate Block Ack requests dropped
Delayed block-ack request sent	Total number of Delayed Block Ack requests sent
Delayed block-ack request received	Total number of Delayed Block Ack requests received
Delayed block-ack request dropped	Total number of Delayed Block Ack requests dropped
Immediate block-ack sent	Total number of Immediate Block Acks sent
Delayed block-ack sent	Total number of Delayed Block Acks sent
Delayed block-ack dropped	Total number of Delayed Block Acks dropped
Block-ack received	Total number of Block Acks received
Packets sent under block-ack policy	Total number of packets sent under Block Ack policy
Packets received under block-ack policy	Total number of packets received under Block Ack policy
Broadcasts sent	Total number of broadcast packets sent
Unicasts received	Total number of unicast packets received
Broadcasts received	Total number of broadcast packets received
CTS packets sent	Total number of CTS packets sent
RTS packets sent	Total number of RTS packets sent
CTS packets received	Total number of CTS packets received
CTS packets dropped	Total number of CTS packets dropped
ACK packets sent	Total number of ACK packets sent
RTS retransmissions due to timeout	Total number of RTS retransmissions due to timeout
Packet retransmissions due to ACK timeout	Total number of packet retransmissions due to ACK timeout
Packet drops due to rts retransmission limit	Total number of packet drops due to rts retransmission limit
Packet drops due to retransmission limit	Total number of packet drops due to retransmission limit

Management Statistics for Infrastructure and Ad-hoc Mode

Table 4-49 lists the management statistics for the 802.11n model.

TABLE 4-49. Management Statistics for 802.11n MAC

Statistics	Description
Management Statistics for Infrastructure and Ad-hoc Modes	
Management packets sent to channel	Total number of management packets sent to channel
Management packets received from channel	Total number of management packets received from channel
Management probe request received	Total number of management probe requests received
Management probe response send	Total number of management probe response send
Management probe response dropped	Total number of management probe response dropped
Management ADDBA request sent	Total number of ADDBA requests sent

TABLE 4-49. Management Statistics for 802.11n MAC (Continued)

Statistics	Description
Management ADDBA request received	Total number of ADDBA requests received
Management ADDBA request dropped	Total number of ADDBA requests dropped
Management ADDBA response sent	Total number of ADDBA response sent
Management ADDBA response received	Total number of ADDBA response received
Management ADDBA response dropped	Total number of ADDBA response dropped
Management DELBA request sent	Total number of DELBA request sent
Management DELBA request received	Total number of DELBA request received
Management DELBA request dropped	Total number of DELBA request dropped
Beacons received	Total number of beacons received
Beacons sent	Total number of beacons sent
Additional Management Statistics for Ad-hoc Mode	
Management probe request generated	Total number of Unicast Probe Requests generated
Management probe request send	Total number of Unicast Probe Requests sent
Management probe request dropped	Total number of Unicast Probe Requests dropped
Management probe response received	Total number of Unicast Probe Response received
Additional Management Statistics for Infrastructure Mode	
Management authentication request received	Total number of management authentication request received
Management authentication response send	Total number of management authentication response send
Management authentication response dropped	Total number of management authentication response dropped
Management association requests received	Total number of management association requests received
Management association response send	Total number of management association response send
Management association response dropped	Total number of management association response dropped
Management reassociation requests received	Total number of management reassociation requests received
Management reassociation response send	Total number of management reassociaiton response send

4.3.6 Sample Scenario

The scenario demonstrates AMSDU and AMPDU data aggregation.

4.3.6.1 Scenario Description

This scenario contains three nodes in one wireless network. One node is an Access Point (AP) and the other two are 802.11n STAs. A CBR application is running between the two STAs.

Topology

Figure 4-30 shows the 802.11n scenario topology.

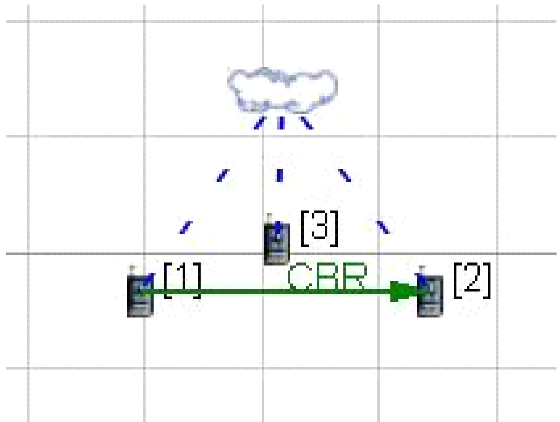


FIGURE 4-30. 802.11n Sample Scenario Topology

4.3.6.2 Command Line Configuration

To configure the sample scenario for the command line, include the following lines in the scenario configuration (.config) file (see Section 3.3 for a description of the PHY parameters):

```
SIMULATION-TIME 30S
APP-CONFIG-FILE   ./Dot11n-Example-Scenario.app

# Physical Layer Parameters
[N8-190.0.0.0] PHY-MODEL PHY802.11n
[N8-190.0.0.0] PHY802.11n-NUM-ANTENNA-ELEMENTS 1
[N8-190.0.0.0] PHY802.11n-SHORT-GI-CAPABLE NO
[N8-190.0.0.0] PHY802.11n-TX-POWER 20.0
[N8-190.0.0.0] PHY802.11n-CHANNEL-BANDWIDTH 20MHz
[N8-190.0.0.0] PHY802.11n-RX-SENSITIVITY-20MHz-MCS0 -82.0
[N8-190.0.0.0] PHY802.11n-RX-SENSITIVITY-20MHz-MCS1 -79.0
[N8-190.0.0.0] PHY802.11n-RX-SENSITIVITY-20MHz-MCS2 -77.0
[N8-190.0.0.0] PHY802.11n-RX-SENSITIVITY-20MHz-MCS3 -74.0
[N8-190.0.0.0] PHY802.11n-RX-SENSITIVITY-20MHz-MCS4 -70.0
[N8-190.0.0.0] PHY802.11n-RX-SENSITIVITY-20MHz-MCS5 -66.0
[N8-190.0.0.0] PHY802.11n-RX-SENSITIVITY-20MHz-MCS6 -65.0
[N8-190.0.0.0] PHY802.11n-RX-SENSITIVITY-20MHz-MCS7 -64.0
[N8-190.0.0.0] PHY-RX-MODEL PHY802.11n

# MAC Layer Parameters
[N8-190.0.0.0] MAC-PROTOCOL MACDOT11e
[N8-190.0.0.0] MAC-DOT11N-ENABLE-DATA-BURSTING NO
[N8-190.0.0.0] MAC-DOT11N-AMSDU-ENABLE YES
[N8-190.0.0.0] MAC-DOT11N-ENABLE-BIG-AMSDU NO
[N8-190.0.0.0] MAC-DOT11N-AMSDU-BUFFER-TIMER-INTERVAL 2MS
[N8-190.0.0.0] MAC-DOT11N-AMPDU-ENABLE YES
[N8-190.0.0.0] MAC-DOT11N-AMPDU-LENGTH-EXPONENT 1
[N8-190.0.0.0] MAC-DOT11N-REORDERING-BUFFER-TIMER-INTERVAL 100MS
[N8-190.0.0.0] MAC-DOT11N-QUEUE-SIZE-PER-DESTINATION 80
[N8-190.0.0.0] MAC-DOT11-ASSOCIATION DYNAMIC
[N8-190.0.0.0] MAC-DOT11-SSID TEST1
[N8-190.0.0.0] MAC-DOT11-AP NO
[N8-190.0.0.0] MAC-DOT11-STA-CHANNEL 0
[N8-190.0.0.0] MAC-DOT11-SCAN-TYPE ACTIVE
```

Include the following line in the application configuration (`Dot11n-Example-Scenario.app`):

```
CBR 1 2 100 512 0.1MS 1S 25S PRECEDENCE 0
```

4.3.6.3 GUI Configuration

Perform the following steps to create this sample scenario using the GUI:

1. Create a new scenario.
2. Go to **Scenario Properties Editor > General > General Settings** and set **Simulation Time** to *30 seconds*.
3. Place three nodes of the Default device type and a wireless subnet on the canvas. Connect all three nodes to the wireless subnet.

4. Go to **Wireless Subnet Properties Editor > Physical Layer** and set **Radio Type** to *802.11n Radio*. See Figure 3-9.
5. Go to **Wireless Subnet Properties Editor > Physical Layer** and set **MAC Protocol** to *802.11e*. See Figure 4-24.
6. Set the following 802.11e MAC parameters (see Figure 4.2.4 for details):
   a. Set **Station Association Type** to *Dynamic*.
   b. Set **Station Scan Type** to *Active*.

   Use the default values for the other parameters.
7. Set **Configure MAC 802.11n Parameters** to *Yes*. See Figure 4-25.
8. Set the following parameters:
   a. Set **Enable AMSDUs** to *Yes*. See Figure 4-26.
   b. Set **AMSDU Buffer Timer** to *2 milli-seconds*. See Figure 4-26.
   c. Set **Enable AMPDUs** to *Yes*. See Figure 4-26.

   Use the default values for the other parameters.
9. Set up a CBR session from node 1 to node 2.
10. Go to **CBR Properties Editor** and set **Interval** to *0.1 milli-seconds*. Use the default values for the other parameters. Refer to *Developer Model Library* for details of configuring CBR.

4.3.7 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the 802.11n MAC protocol. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/dot11n. Table 4-50 lists the sub-directory where each scenario is located.

TABLE 4-50. 802.1n MAC Scenarios Included in EXata

Name	Description
amsdu_test	Demonstrates communication from one STA to another STA with AMSDU aggregation.
ampdu_test	Demonstrates communication from one STA to another STA with AMPDU aggregation.
short_gi_test	Demonstrates throughput enhancement using short guard interval.
throughput_test	Demonstrates throughput enhancement using various antenna elements.
ad-hoc_test	Demonstrates 802.11n functionalities in ad-hoc mode.

4.3.8 References

- IEEE 802.11n–2009. “Enhancements for Higher Throughput.” 29 October, 2009.

4.4 802.11s MAC Protocol

The EXata 802.11s MAC protocol is based on the following documents:

- draft P802.11s/D0.02.
- IEEE Std 802.11–1999.
- The IEEE 802.11 Handbook A Designer's Companion:A Designers Companion.

4.4.1 Description

The 802.11s MAC protocol aims to standardize wireless connectivity for multiple hops within the 802.11 framework. End-to-end connectivity across a wireless medium requires that each device connects to one or more neighbors so that a mesh can form. The resulting mesh permits selection of one of the multiple paths for end-point delivery.

IBSS (Independent Basic Service Set), or ad-hoc networks, use layer 3 route selection and offer a single IP hop between peers. In comparison, Mesh networks use a layer 2 mechanism to determine optimal paths within the mesh and permit multiple MAC layer hops between a single IP hop.

AP (Access Point) that form infrastructure or BSS (Basic Service Set) networks, typically interconnect to each other via a wired infrastructure such as an 802.11 switched LAN. For traffic between BSS networks, mesh services enable secure wireless interoperability.

While 802.11 has evolved to higher radio speeds and resulting shorter range, the overall deployment and coverage distance remains the same. Mesh services offer a multiple hop solution across such distances that do not increase the need for cabling and reduces deployment time.

Mesh services extend existing 802.11 services. A mesh enabled station is termed as Mesh Point. A mesh point or MP may also offer AP or portal services. Mesh points are envisaged to be dedicated devices, such as APs that manage BSS stations or forward traffic, or end-user equipment such as digital TVs, cameras or printers.

The 802.11s draft specifies formation of mesh networks that provide self-configuring neighbor discovery, peer association, path discovery and forwarding. It also addresses interconnectivity with other non-802.11 and IP networks.

4.4.2 Features and Assumptions

This section describes the implemented features, omitted features, assumptions and limitations of the 802.11s MAC model.

4.4.2.1 Implemented Features

A list of 802.11s MAC features implemented in EXata are as follows:

- 802.11 stations provide mesh services. These are termed as Mesh Points (MPs).
- MPs independently offer Access Point services (MAPs).
- At inter-networking points, MPs offer Portal functionality (MPPs).
- Cover mesh management and operations.
- Cover path protocol and path metric interfaces.

Mesh Management

Managing Mesh properties consists of the following sections:

- MP Initialization

- MPs provide a 5 stage initialization process.
- Attempt to adjust beacon offset to minimize collision.
- Block upper layer traffic during this phase.
- Stations cannot associate with MAPs during this phase.

- Neighbor Discovery
  - Passive mode neighbor discovery by listening to beacons.
  - Beacon frames use mesh information elements to advertise capabilities.
  - Mesh profiles within beacons identify candidate mesh neighbors.
- Peer Link Establishment
  - Mesh peers use 4-way handshake.
  - Exchange Open and Confirm association frames.
  - Link establishment is rate limited.
- Link State Measure and Exchange
  - Link quality is measured using path metric.
  - The super-ordinate MP communicates link quality to peers.
  - Link state measures used for optimal radio-aware path selection.
- Peer Link Maintenance
  - Periodic link state exchanges update link quality measures.
  - Unsuccessful link state exchanges determine termination of link.

Single or multiple path options may be available to an MP under mobility.	Long paths vary form as a result of mobility. For node 10, the path to the rest of the mesh is via nodes 4 and 5.	Temporary loss of connectivity and isolation of a mesh node can result from neighbors not in range - node 9 is discon nected from the rest of the mesh.

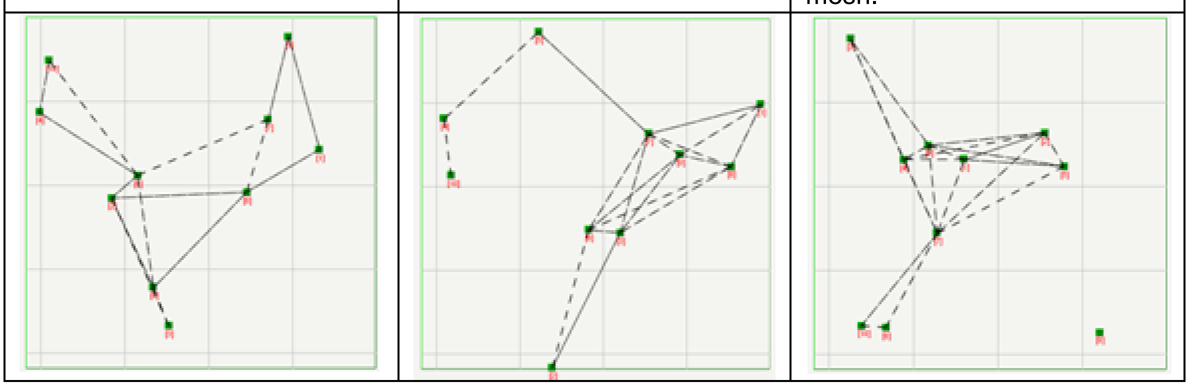


FIGURE 4-31. Link Maintenance under Mobility for 10 Mesh Points in a 1000 m x 1000 m Terrain

- Mesh portals
  - Interfaces with other subnets.
  - Uses Layer-3 inter-connectivity, i.e. IP.
  - Sends periodic portal announcements.
  - MPs select optimal parent to portal.

- MPs propagate announcements to rest of mesh.

Hybrid Wireless Mesh Protocol (HWMP)

HWMP is the default path protocol for 802.11s MAC. It uses AODV primitives and has been extended to use radio-aware metrics, not hop count. It has also been extended for proactive tree formation.

- Default path protocol for 802.11s MAC.
- Uses AODV primitives.
- Extended to use radio metrics, not hop count.
- Extended for proactive tree formation.

- Triggered Route Requests
  - RREQ broadcasts used for on-demand route discovery.
  - Relay subject to TTL/hop count limits, nodes, and other flags.
  - Configurable for expanding-ring or full TTL mechanism.
  - MPs proxy for associated stations.
- Route replies
  - Configurable as destination node only or as an intermediate.
  - Best path at each hop uses link state measures.
  - Destination proxies for associated stations.
- Route errors
  - Maintain routes on link failure or termination.
  - Notifies precursors with active routes.
  - May be broadcast or unicast.
- Root and root announcements
  - Enables proactive spanning tree formation.
  - Single configurable root per mesh.
  - Periodic root announcement indicates active root.
  - MPs select best parent towards root.
  - MPs relay announcements to rest of mesh.
  - MPs may register with root for bi-directional tree.
  - MPs use legacy mechanism for proxy registration.
  - Spanning tree changes dynamically.

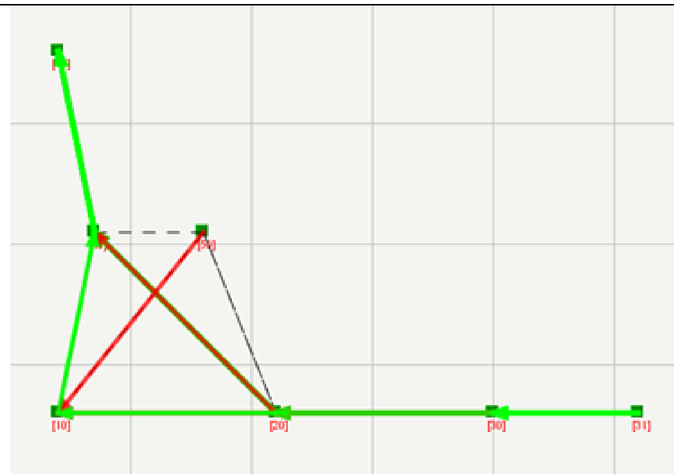
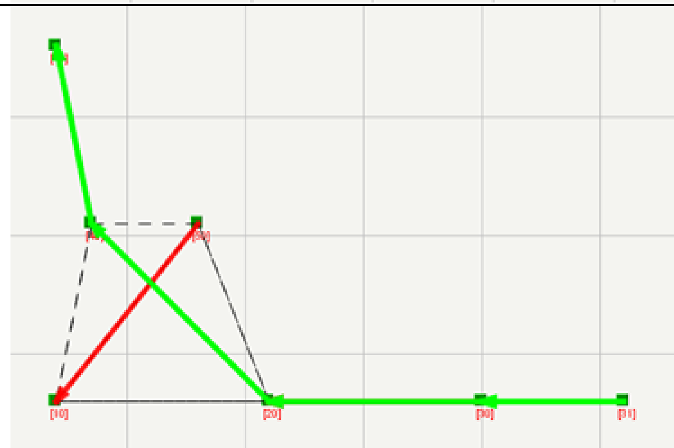
In presence of an HWMP root (node 10, lower left in the diagram), the initial packet is forwarded along the tree as shown by the green arrows.	
Subsequent adhoc route discovery finds a more optimal path, and this is used for packet forwarding.	

FIGURE 4-32. Proactive and Reactive routing

Airtime Link Metric (ATLM)

- Default path metric for 802.11s MAC
- Measures link quality in terms of data rate and PER.
- Used by mesh management and path protocol.
- Computes link cost in micro-seconds for 1000 byte payload.

Frame forwarding

- Uses four address frame format.
- Translates to/from 3 address format for station proxy.
- Uses signature cache for broadcast loops.
- Uses TTL and association information to limit relays.
- Works in conjunction with path protocol.

4.4.2.2 Omitted Features

Features not implemented in this development are:

- Channel convergence.
- Authentication between MPs.

- Layer 2 inter-connectivity with other IEEE LANs.
- AODV's blacklist and local repair capability.
- HWMP route maintenance.
- NULL metric and path protocol.
- Use of 6-address format for frame forwarding.
- End-to-end ordering.
- Non-forwarding or light-weight MPs.
- Support for QoS, congestion control or MDA.
- Power save mode.

4.4.2.3 Assumptions and Limitations

- There is no QoS Support, deterministic access, congestion control, power save or channel negotiation.

4.4.3 Command Line Configuration

The 802.11s MAC model is automatically enabled if the MAC protocol is configured to be 802.11 MAC in infrastructure mode.

Section 4.4.3.1 describes the parameters for mesh point configuration. Section 4.4.3.2 describes the parameters for the HWMP (Hybrid Wireless Mesh Protocol) configuration.

See Section 1.2.1.3 for a description of the format used for the parameter tables.

Configuration Requirements

To run 802.11s MAC, the MAC protocol must be configured to be 802.11 MAC in infrastructure mode, that is, `MAC-PROTOCOL` must be set to `MACDOT11` and `MAC-DOT11-ASSOCIATION` must be set to `DYNAMIC`.

See Section 4.1 for details of configuring 802.11 MAC.

4.4.3.1 Mesh Point Configuration

Table 4-51 describes the mesh point configuration parameters.

TABLE 4-51. Mesh Point Configuration Parameters

Parameter	Value	Description
MAC-DOT11s-MESH-ID *Optional* *Scope:* All	String *Default:* Mesh1	Configures mesh identifiers. Mesh points with a common mesh identifier can associate to form a mesh network. **Note:** The mesh ID can have at most 32 characters.
MAC-DOT11s-MESH-POINT *Optional* *Scope:* Node, Interface	List: • YES • NO *Default:* NO	Configures the node or interface as a Mesh-enabled node, or Mesh Point (MP). MPs provide self-configuring neighbor discovery, peer link setup, and path selection. **Notes:** Mesh services can be configured for a station or an AP. QoS is not supported for mesh points. Mesh services can not be configured for an HC (Hybrid Coordinator). Mesh-enabled nodes do not support power-save features.
MAC-DOT11s-MESH-PORTAL *Optional* *Scope:* Node, Interface	List: • YES • NO *Default:* NO	Configures the MP as a portal. Portals provide inter-connectivity with other meshes, 802.11 LANs or IP subnets. Currently a portal interconnects using upper layer services and does not provide Layer 2 bridging.
MAC-DOT11s-PORTAL-ANNOUNCEMENT-PERIOD *Optional* *Scope:* Node, Interface	Time *Range:* ≥ 0S *Default:* 4S	Configures the interval between periodic announcements by a mesh portal. This announcement propagates through the mesh.
MAC-DOT11s-PATH-PROTOCOL *Optional* *Scope:* All	List: • HWMP *Default:* HWMP	Configures the path protocol to be used for route discovery and path selection. HWMP is the only option currently available.
MAC-DOT11s-PATH-METRIC *Optional* *Scope:* All	List: • AIRTIME *Default:* AIRTIME	Configures the path metric to be used for path costs. AIRTIME link metric is the only option currently available.
MAC-DOT11s-LINK-SETUP-RATE-LIMIT *Optional* *Scope:* All	Integer *Range:* ≥ 0 *Default:* 1	Configures the maximum number of links to establish per Link Setup Period. **Note:** A value of 0 indicates no limit.

TABLE 4-51. Mesh Point Configuration Parameters (Continued)

Parameter	Value	Description
`MAC-DOT11s-NET-DIAMETER` *Optional* *Scope:* All	Integer *Range:* `[0, 256]` *Default:* `7`	Configures the net diameter for the mesh. This is the maximum number of hops between two MPs in a mesh. The draft recommends a value of 20; but a smaller value is used here as it is also the maximum value of TTL used in frame transmissions and will be accessed by path protocols (such as HWMP for expanding ring search). The value should be conservative and should account for long paths that could occur under mobility. As a rule-of-thumb, each hop reduces the throughput by at least half. In practice, a reasonable estimate is that an MP would not be more than 4 hops away from an inter-network point.
`MAC-DOT11s-NODE-TRAVERSAL-TIME` *Optional* *Scope:* All	Time *Range:* ≥ `0S` *Default:* `100MS`	Configures estimated average one-hop traversal time. This should be a conservative estimate and should include queuing, transmission, propagation and other delays. The draft recommends a value of 40MS but a larger value is used to accommodate non-QoS behavior as this value is also accessed by path protocols (such as HWMP for reverse route lifetime). Currently, MPs do not support priority (802.11e) and control packets but may experience delays in a single management queue. In this queue the neighbors are at the edge of the range or in dense scenarios where the sum of back-off for transmit attempts can increase traversal delays.
`MAC-DOT11s-PORTAL-TIMEOUT` *Optional* *Scope:* Node, Interface *Instances:* No	Time *Range:* ≥ `0S` *Default:* `10S`	Configures lifetime of a received portal announcement. A MP considers a portal active after receiving its last portal announcement. The value could be same as the route timeout of the path protocol. **Note:** Since portal announcements do no carry a lifetime value, this value applies to aging of all portals. **Note:** The default value for the active portal timeout is set to 2.5 * portal announcement period.
`MAC-LAYER-STATISTICS` *Optional* *Scope:* All	List: • `YES` • `NO` *Default:* `NO`	Indicates whether statistics are collected for MAC layer protocols, including 802.11s.

4.4.3.2 HWMP Configuration

Table 4-52 describes the HWMP configuration parameters. The three key settings, namely the route discovery type, destination only flag, and presence of root, affects how the initial packets in a traffic flow behave and the contention affect on the rest of the mesh for the duration of such broadcasts.

Expanding ring search finds paths with low hop count quickly and limits the broadcast effect locally. Full TTL route discovery results in mesh-wide forward paths to source node, but broadcast propagation is maximum.

Setting of the destination-only flag to FALSE allows the nearest intermediate node to respond to a route request and packet forwarding to start early, and is best used in combination with expanding ring.

The draft seems to indicate a preference for Full TTL combined with destination only replies. Note that expanding ring discovery finds no specific mention in the latest draft compared to it being an “optional enhancement” in the previous versions.

Presence of a root and resulting creation of proactive routes has the overhead of root announcements and root validation. Proactive routes help forward the initial packets quickly while route discovery is in progress. The balancing of overall traffic against the proactive mode overhead has to be judged. One of the portals would typically be the root. A root need not necessarily be an MPP, it can also be centrally placed in the mesh so that the tree formed has a low depth.

TABLE 4-52. HWMP Configuration Parameters

Parameter	Value	Description
`MAC-DOT11s-HWMP-ACTIVE-ROUTE-TIMEOUT` *Optional* *Scope:* All	Time *Range:* (see note) *Default:* `5S`	Configures the lifetime of an active route for HWMP. When a directed data frame is sent, the lifetime of the route is updated to a minimum of this value. **Note:** The value should be greater than or equal to (2 * `MAC-DOT11s-NET-DIAMETER * MAC-DOT11s-NODE-TRAVERSAL-TIME`)
`MAC-DOT11s-HWMP-MY-ROUTE-TIMEOUT` *Optional* *Scope:* All	Time *Range:* (see note) *Default:* `10S` (see note)	Configures the lifetime of a route when replied by destination. **Note:** The default is 10 sec (2 * `MAC-DOT11s-HWMP-ACTIVE-ROUTE-TIMEOUT`) **Note:** The value should be greater than or equal to `MAC-DOT11s-HWMP-ACTIVE-ROUTE-TIMEOUT`.
`MAC-DOT11s-HWMP-REVERSE-ROUTE-TIMEOUT` *Optional* *Scope:* All	Time *Range:* (see note) *Default:* `10S` (see note)	Configures the lifetime of a route under discovery. This value is used by routes created as a result of receiving a RREQ. **Note:** The value should be greater than or equal to (2 * `MAC-DOT11s-NET-DIAMETER * MAC-DOT11s-NODE-TRAVERSAL-TIME`) **Note:** The default is 10 sec (2 * `MAC-DOT11s-HWMP-ACTIVE-ROUTE-TIMEOUT`)
`MAC-DOT11s-HWMP-ROUTE-DELETION-CONSTANT` *Optional* *Scope:* All	Integer *Range:* ≥ `0S` *Default:* `5`	Configures the constant used for route deletion. An inactive route is deleted from the routing table after (constant * active route timeout) interval.

TABLE 4-52. HWMP Configuration Parameters (Continued)

Parameter	Value	Description
MAC-DOT11s-HWMP-ROUTE-DISCOVERY-TYPE *Optional* *Scope:* All	List: • EXPANDING-RING • FULL-TTL *Default:* EXPANDING-RING	Configures the ad-hoc route discovery algorithm. An expanding ring search starts by sending an RREQ with a smaller TTL and resends it with increasing TTL if a response is not received. The full TTL search sends the initial and subsequent RREQs using the net diameter value as TTL.
MAC-DOT11s-HWMP-RREQ-TTL-INITIAL *Optional* *Scope:* All	Integer *Range:* (see note) *Default:* 2	Configures the initial value of RREQ TTL for expanding the ring route discovery. **Note:** This should be less than or equal to MAC-DOT11s-NET-DIAMETER
MAC-DOT11s-HWMP-RREQ-TTL-INCREMENT *Optional* *Scope:* All	Integer *Range:* ≥ 0S *Default:* 2	For expanding ring route discovery, configure the increment to the TTL for an RREQ retransmit. The TTL is increased by 2 over the previous RREQ TTL value.
MAC-DOT11s-HWMP-RREQ-TTL-THRESHOLD *Optional* *Scope:* All	Integer *Range:* (see note) *Default:* (see note)	Configures the value beyond which TTL is set to net diameter, for expanding ring route discovery **Note:** The value should be greater than or equal to MAC-DOT11s-HWMP-RREQ-TTL-INITIAL and less than or equal to MAC-DOT11s-NET-DIAMETER. **Note:** The default is the minimum of MAC-DOT11s-NET-DIAMETER and 5.
MAC-DOT11s-HWMP-RREQ-MAX-TTL-ATTEMPTS *Optional* *Scope:* All	Integer *Range:* ≥ 0S *Default:* (see note)	Configures the number of attempts using an RREQ with maximum TTL. **Note:** The default value is 2 for expanding ring route discovery and 3 for full TTL route discovery.
MAC-DOT11s-HWMP-RREQ-DESTINATION-ONLY *Optional* *Scope:* All	List: • YES • NO *Default:* YES	Configures the RREQ destination only flag used for route discovery. YES: Only the destination responds to the RREQ. NO: The intermediate nodes may send a response.
MAC-DOT11s-HWMP-RREQ-REPLY-AND-FORWARD *Optional* *Scope:* All	List: • YES • NO *Default:* YES	Configures the reply-and-forward flag used for route discovery. The flag is applicable only when the RREQ destination-only flag is off. YES : An intermediate node that sends a response will also forward the RREQ to destination. NO : The destination may be unaware of the route request.

TABLE 4-52. HWMP Configuration Parameters (Continued)

Parameter	Value	Description
`MAC-DOT11s-HWMP-ROOT` *Optional* *Scope:* All	List: • `YES` • `NO` *Default:* `NO`	Configures the MP as a root for HWMP proactive mode. A root would initiate the creation of minimal metric spanning tree that may be used for forwarding within the mesh.
`MAC-DOT11s-HWMP-ROOT-ANNOUNCEMENT-PERIOD` *Optional* *Scope:* All	Time *Range:* ≥ `0S` *Default:* `4S`	Configures the period between root announcements by a HWMP root MP.
`MAC-DOT11s-HWMP-ROOT-REGISTRATION` *Optional* *Scope:* All	List: • `YES` • `NO` *Default:* `YES`	Configures when a root requests registration from MPs so that paths from root to MP are also created for proactive routing. If `NO`, paths from root to MPs are not automatically built.
`MAC-DOT11s-HWMP-ROOT-TIMEOUT` *Optional* *Scope:* All	Time *Range:* (see note) *Default:* `10S` (see note)	Configures the lifetime for the path to root. If it is not specified, the default value matches that of the on-demand my route lifetime (`MAC-DOT11s-HWMP-MY-ROUTE-TIMEOUT`). **Note:** The default is about 2.5 * root announcement period allowing two root announcements to be missed before deactivating proactive mode**.** **Note:** `MAC-DOT11s-HWMP-ROOT-TIMEOUT` should be greater than `MAC-DOT11s-HWMP-ROOT-ANNOUNCEMENT-PERIOD`.

4.4.4 GUI Configuration

This section describes how to configure 802.11s MAC in the GUI.

Configuring 802.11s MAC Parameters

To configure the general 802.11s MAC parameters, perform the following steps:

1. Go to one of the following locations:

- To set properties at the subnet level, go to **Wireless Subnet Properties Editor > MAC Layer**.
- To set properties at the interface level, go to one of the following locations:
  - **Interface Properties Editor > Interfaces > Interface # > MAC Layer**.
  - **Default Device Properties Editor > Interfaces > Interface # > MAC Layer**.

In this section, we show how to configure the general 802.11s MAC parameters in the Interfaces tab of the Default Device Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **MAC Protocol** to *802.11.*

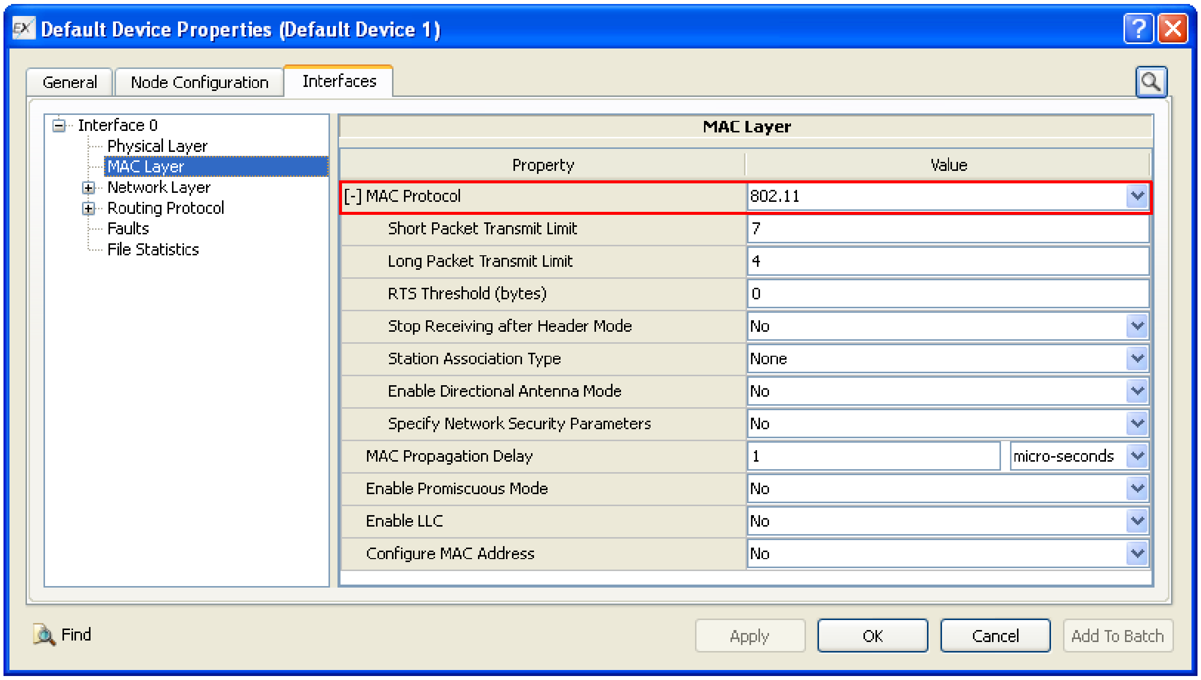


FIGURE 4-33. Selecting 802.11 MAC as MAC Protocol

Setting Parameters

- Set the general 802.11 MAC parameters, as described in Section 4.1.3.1.

3. Set **Station Association Type** to *Dynamic*.

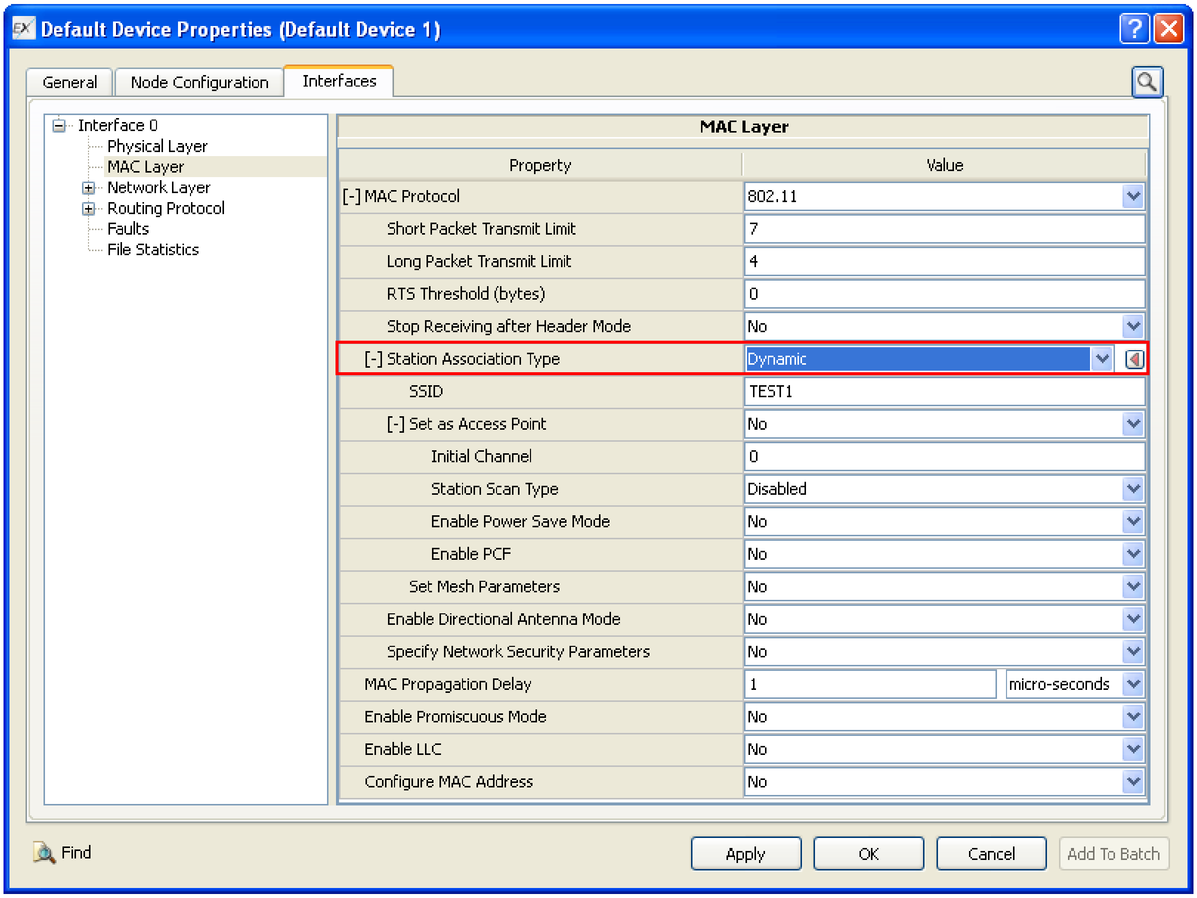


FIGURE 4-34. Selecting Infrastructure Mode

Setting Parameters

- Set the 802.11 MAC infrastructure mode parameters, as described in Section 4.1.3.3.

4. Set **Set Mesh Parameters** to *Yes* and set the dependent parameters listed in Table 4-53.

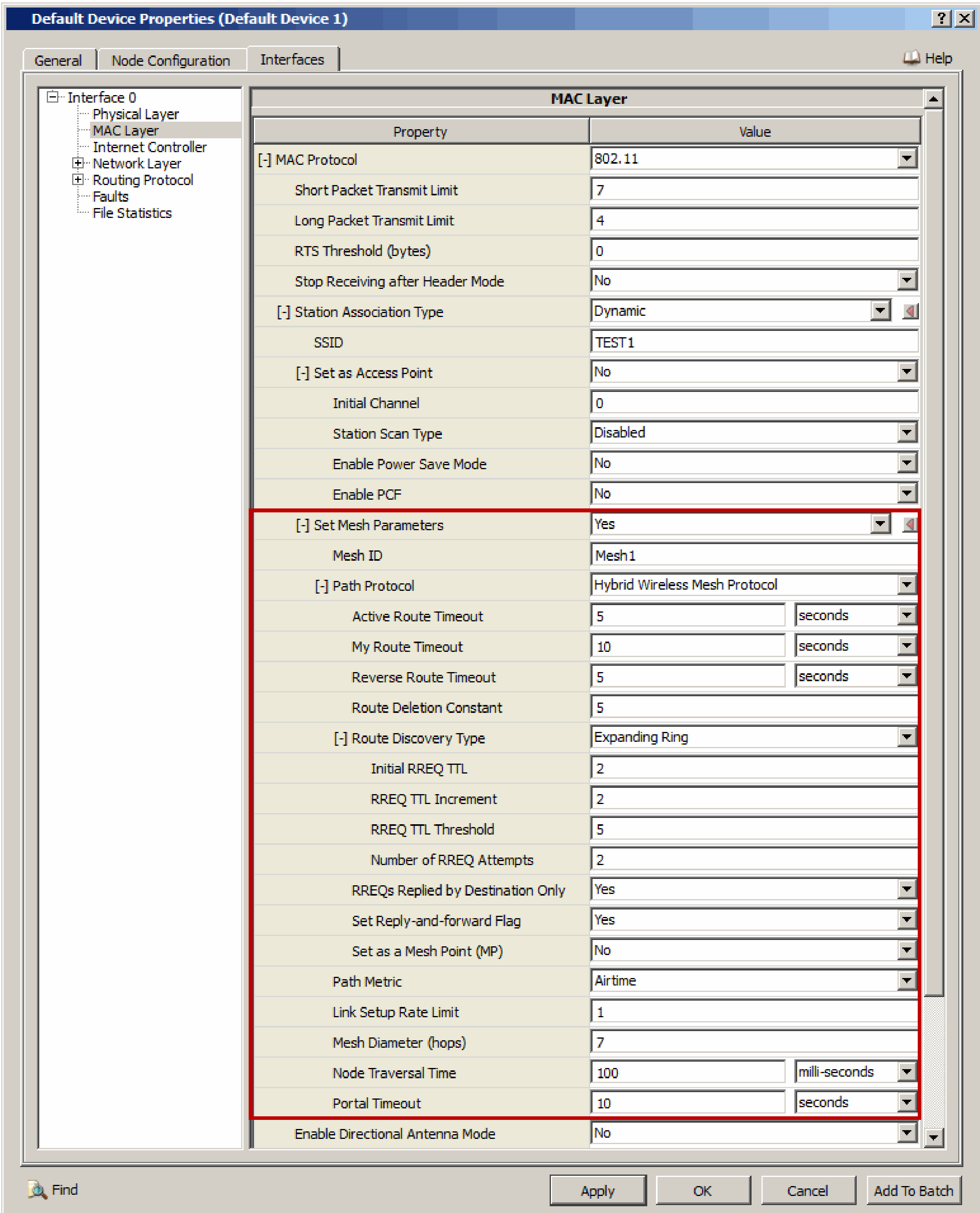


FIGURE 4-35. Setting 802.11s MAC Mesh Parameters

TABLE 4-53. Command Line Equivalent of General 802.11s MAC Mesh Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Mesh ID	Subnet, Interface	`MAC-DOT11s-MESH-ID`
Path Protocol	Subnet, Interface	`MAC-DOT11s-PATH-PROTOCOL`
Active Route Timeout	Subnet, Interface	`MAC-DOT11s-HWMP-ACTIVE-ROUTE-TIMEOUT`
My Route Timeout	Subnet, Interface	`MAC-DOT11s-HWMP-MY-ROUTE-TIMEOUT`
Reverse Route Timeout	Subnet, Interface	`MAC-DOT11s-HWMP-REVERSE-ROUTE-TIMEOUT`
Route Deletion Constant	Subnet, Interface	`MAC-DOT11s-HWMP-ROUTE-DELETION-CONSTANT`
Route Discovery Type	Subnet, Interface	`MAC-DOT11s-HWMP-ROUTE-DISCOVERY-TYPE`
Initial RREQ TTL	Subnet, Interface	`MAC-DOT11s-HWMP-RREQ-TTL-INITIAL`
RREQ TTL Increment	Subnet, Interface	`MAC-DOT11s-HWMP-RREQ-TTL-INCREMENT`
RREQ TTL Threshold	Subnet, Interface	`MAC-DOT11s-HWMP-RREQ-TTL-THRESHOLD`
Number of RREQ Attempts	Subnet, Interface	`MAC-DOT11s-HWMP-RREQ-MAX-TTL-ATTEMPTS`
RREQs Replied by Destination Only	Subnet, Interface	`MAC-DOT11s-HWMP-RREQ-DESTINATION-ONLY`
Set Reply-and-forward Flag	Subnet, Interface	`MAC-DOT11s-HWMP-RREQ-REPLY-AND-FORWARD`
Set as Mesh Point	Interface	`MAC-DOT11s-MESH-POINT`
Path Metric	Subnet, Interface	`MAC-DOT11s-PATH-METRIC`
Link Setup Rate Limit	Subnet, Interface	`MAC-DOT11s-LINK-SETUP-RATE-LIMIT`
Mesh Diameter(hops)	Subnet, Interface	`MAC-DOT11s-NET-DIAMETER`
Node Traversal Time	Subnet, Interface	`MAC-DOT11s-NODE-TRAVERSAL-TIME`
Portal Timeout	Subnet, Interface	`MAC-DOT11s-PORTAL-TIMEOUT`

Setting Parameters

- To configure a node as a mesh point, set **Set as a Mesh Point (MP)** to *Yes*; otherwise, set **Set as a Mesh Point (MP)** to *No*.

5. If **Set as a Mesh Point (MP)** is set to *Yes*, then set the dependent parameters listed in Table 4-54.

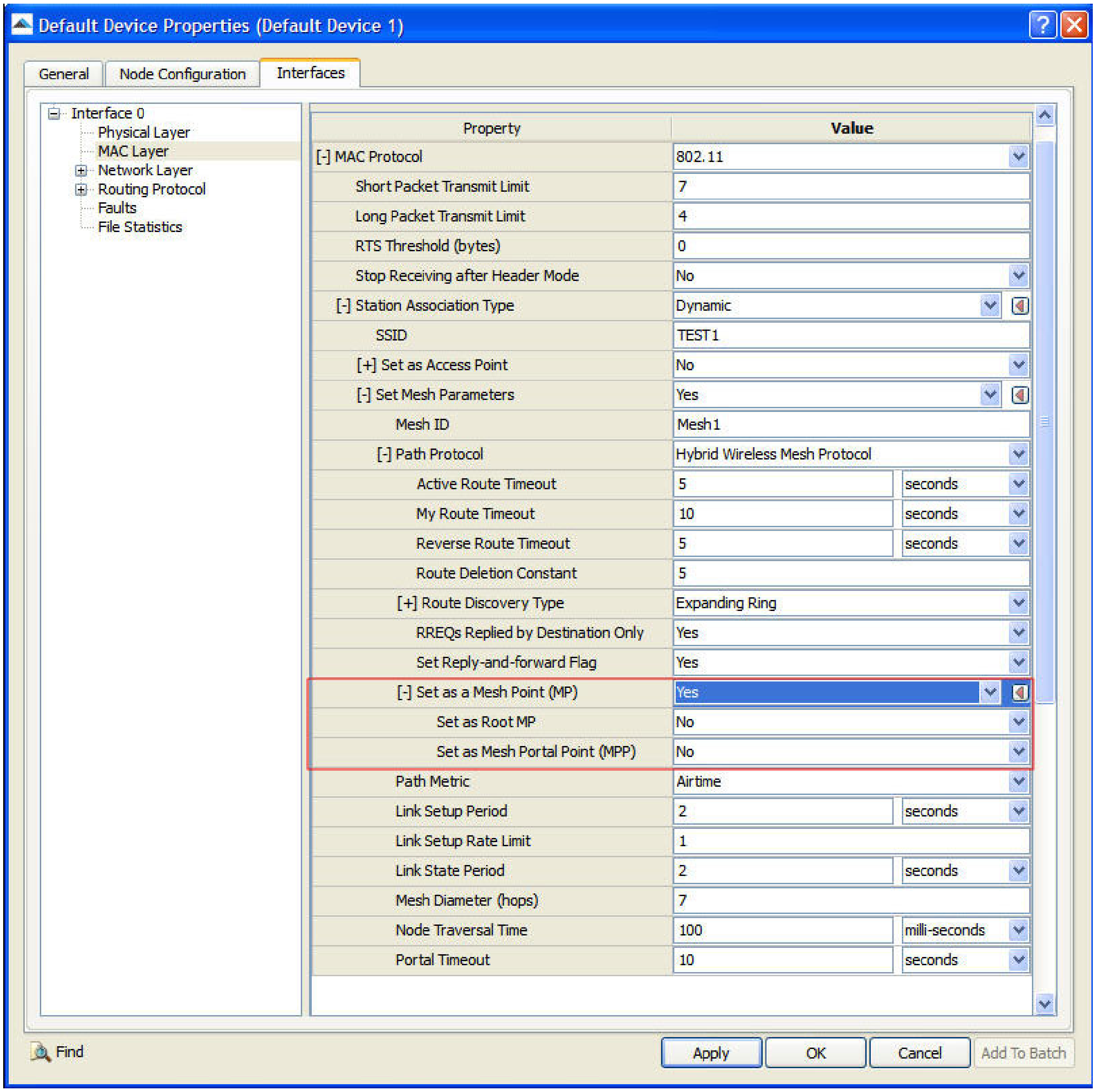


FIGURE 4-36. Setting 802.11s MAC Mesh Point Parameters

TABLE 4-54. Command Line Equivalent of 802.11s MAC Mesh Point Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Set as Root MP	Interface	`MAC-DOT11s-HWMP-ROOT`
Set as Mesh Portal Point (MPP)	Interface	`MAC-DOT11s-MESH-PORTAL`

Setting Parameters

- To configure Mesh Point as Root MP, set **Set as Root MP** to *Yes*; otherwise, set **Set as Root MP** to *No*.
- To configure Mesh Point as Mesh Portal Point, set **Set as Mesh Portal Point (MPP)** to *Yes*; otherwise, set **Set as Mesh Portal Point (MPP)** to *No*.

6. If **Set as Root MP** is set to *Yes*, then set the dependent parameters listed in Table 4-55.

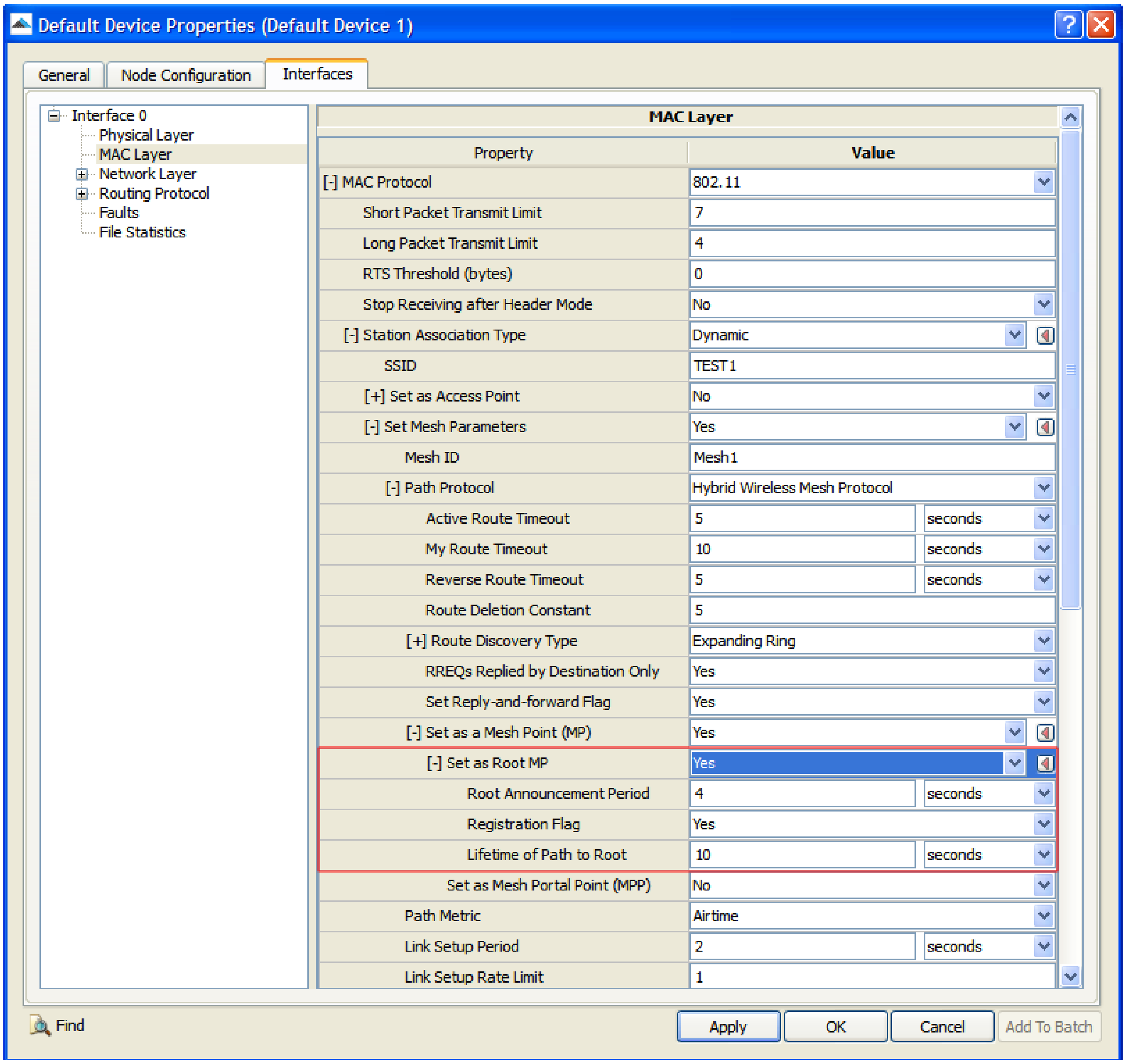


FIGURE 4-37. Configuring Root MP Parameters

TABLE 4-55. Command Line Equivalent of 802.11s MAC Root MP Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Root Announcement Period	Interface	`MAC-DOT11s-HWMP-ROOT-ANNOUNCEMENT-PERIOD`
Registration Flag	Interface	`MAC-DOT11s-HWMP-ROOT-REGISTRATION`
Lifetime of Path to Root	Interface	`MAC-DOT11s-HWMP-ROOT-TIMEOUT`

7. If **Set as Mesh Portal Point (MPP)** is set to *Yes*, then set the dependent parameters listed in Table 4-56.

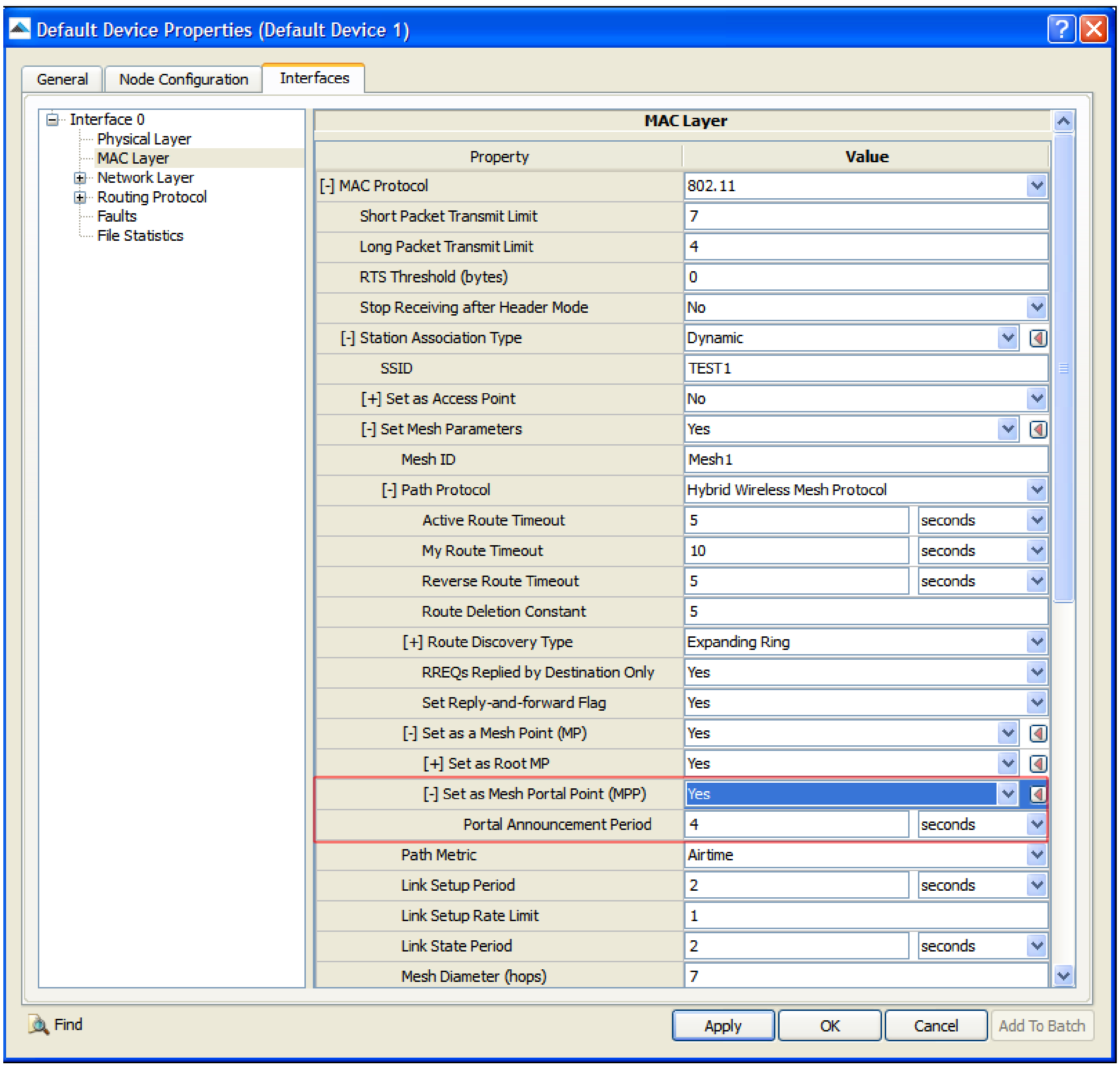


FIGURE 4-38. Configuring Mesh Portal Point Parameters

TABLE 4-56. Command Line Equivalent of 802.11s MPP Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Portal Announcement Period	Interface	`MAC-DOT11s-PORTAL-ANNOUNCEMENT-PERIOD`

Configuring Statistics Parameters

Statistics for 802.11s MAC can be collected at the global, node, subnet, and interface levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for MAC protocols including 802.11s MAC, check the box labeled **MAC** in the appropriate properties editor.

TABLE 4-57. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
MAC	Global, Node, Subnet, Interface	`MAC-LAYER-STATISTICS`

4.4.5 Statistics

This section describes the 802.11s MAC statistics that are output to the statistics (.stat) file at the end of simulation.

Table 4-58 shows the mesh management statistics collected for the 802.11s MAC model.

TABLE 4-58. 802.11s MAC Mesh Management Statistics

Statistic	Description
Mesh beacons sent	Number of beacons sent with mesh IEs.
Mesh beacons received	Number of beacons received from within the mesh.
Mesh association requests sent	Number of association requests enqueued for sending to mesh neighbors.
Mesh association requests received	Number of association requests received from mesh neighbors.
Mesh association responses sent	Number of association responses enqueued for sending to mesh neighbors.
Mesh association responses received	Number of association responses received from mesh neighbors.
Mesh association close sent	Number of association close frames sent to mesh neighbors.
Mesh association close received	Number of association close frames received from mesh neighbors.
Mesh link state announcements sent	Number of link state announcements enqueued for sending to mesh neighbors.
Mesh link state announcements received	Number of link state announcements received from mesh neighbors.
Mesh portal announcements initiated	Number of portals announcements initiated. Value would be zero for non-portals.
Mesh portal announcements relayed	Number of portal announcements relayed.

TABLE 4-58. 802.11s MAC Mesh Management Statistics (Continued)

Statistic	Description
Mesh portal announcements received	Number of portal announcements received.
Mesh portal announcements dropped	Number of portal announcements dropped, typically duplicates.
Mesh management broadcasts dropped	Cumulative count of all the mesh management broadcast frames dropped.
Mesh management unicasts dropped	Cumulative count of all the mesh management unicasts dropped.
Mesh queue management broadcasts dropped	Number of enqueued management broadcast frames dropped.
Mesh queue management unicasts dropped	Number of enqueued management unicast frames dropped due to the link failure or expiry of lifetime.

Table 4-59 shows the mesh data frames statistics collected for the 802.11s MAC model.

TABLE 4-59. 802.11s MAC Mesh Data Frames Statistics

Statistic	Description
Mesh data broadcasts sent to Network layer	Number of data broadcast frames sent to upper layer.
Mesh data unicasts sent to Network layer	Number of data unicast frames sent to the upper layer.
Mesh data broadcasts received from Network layer	Number of data broadcast frames passed down from the upper layer.
Mesh data unicasts received from Network layer	Number of data unicast frames passed down from the upper layer.
Mesh data broadcasts sent to BSS	Number of data broadcasts sent to the BSS. For a MP without AP functionality, this is zero.
Mesh data broadcasts sent to mesh	Number of data broadcast frames sent to mesh.
Mesh data broadcasts received from BSS as unicasts	Number of data broadcast frames received from BSS. Value is zero for non-APs.
Mesh data broadcasts received from mesh	Number of data broadcast frames received from the mesh neighbors.
Mesh data broadcasts dropped	Number of data broadcast frames that were not processed; either duplicate frames or frames received from non-associated neighbors.
Mesh data unicasts sent to BSS	Number of unicast frames sent to the BSS. Value is zero for non-APs.
Mesh data unicasts sent to mesh	Number of unicast frames enqueued for sending to the mesh.
Mesh data unicasts received from BSS	Number of unicast frames received from the BSS. Value is zero for non-APs.
Mesh data unicasts received from mesh	Number of data unicasts received from the mesh.
Mesh data unicasts relayed to BSS from BSS	Number of relayed unicast frames with source and destination as the BSS. Value is zero for non-APs.
Mesh data unicasts relayed to BSS from mesh	Number of data unicast frames relayed to the BSS that were received from mesh. Value is zero for non-APs.
Mesh data unicasts relayed to mesh from BSS	Number of data unicast frames relayed to mesh from BSS. Value is zero for non-APs.
Mesh data unicasts relayed to mesh from mesh	Number of data unicast frames received from mesh and relayed to mesh.
Mesh data unicasts sent to routing function	Cumulative number of data unicast frames sent to routing function, except those relayed within the BSS.

TABLE 4-59. 802.11s MAC Mesh Data Frames Statistics (Continued)

Statistic	Description
Mesh data unicasts dropped	Number of data unicast frames dropped.
Mesh queue data broadcasts dropped	Number of enqueued data broadcast frames dropped.
Mesh queue data unicasts dropped	Number of enqueued data unicast frames dropped. Reason could be link failure or expiry of lifetime.

Table 4-60 shows HWMP frames statistics collected for the 802.11s MAC model.

TABLE 4-60. 802.11s MAC HWMP Frames Statistics

Statistic	Description
HWMP RREQ broadcasts initiated	Number of route requests initiated as broadcasts.
HWMP RREQ unicasts initiated	Number of route requests initiated as unicasts. Such frames are used for root registration.
HWMP RREQs retried	Number of route requests needed to be retried for lack of reply.
HWMP RREQs forwarded	Number of route requests that were forwarded by the intermediate nodes.
HWMP RREQs received	Total number of route requests received.
HWMP RREQs received (destination)	Number of route requests received as destination. Destination could be a BSS station for APs.
HWMP RREQs discarded (duplicate)	Number of route requests dropped because they were duplicates.
HWMP RREQs discarded (TTL expired)	Number of route requests dropped because TTL was zero.
HWMP RREPs initiated (destination)	Number of route replies initiated as destination. Destination could be a BSS station for APs.
HWMP RREPs initiated (intermediate)	Number of route replies initiated by intermediate nodes.
HWMP RREPs forwarded	Number of route replies relayed or forwarded.
HWMP RREPs received	Cumulative number of route replies received.
HWMP RREPs received (source)	Number of route replies received as the source of route request. Source could be a BSS station.
HWMP Gratuitous RREPs initiated	Number of gratuitous route replies sent. Such RREPs may be sent as part of HWMP proactive tree formation.
HWMP Gratuitous RREPs forwarded	Number of gratuitous route replies forwarded. Such RREPs are sent towards the root.
HWMP Gratuitous RREPs received	Number of gratuitous RREPs received from downstream children.
HWMP RERRs initiated	Number of route errors initiated.
HWMP RERRs forwarded	Number of route errors forwarded.
HWMP RERRs received	Number of route errors received.
HWMP RERRs discarded	Number of route errors discarded.
HWMP RANNs initiated	Number of root announcements initiated. Value is zero for a non-root.
HWMP RANNs forwarded	Number of root announcements forwarded.
HWMP RANNs received	Cumulative number of root announcements received.
HWMP RANNs discarded (duplicate)	Number of root announcements discarded because they were duplicates.
HWMP RANNs discarded (TTL expired)	Number of root announcements discarded because the TTL had reached zero.

TABLE 4-60. 802.11s MAC HWMP Frames Statistics (Continued)

Statistic	Description
HWMP Data packets sent (source or BSS)	Number of data unicast frames sent where MP is either a source or proxying for BSS stations.
HWMP Data packets forwarded	Number of data unicasts forwarded as the route to destination was available.
HWMP Data packets received	Number of data unicast frames received, where MP or one of the station is proxying the destination.
HWMP Data packets dropped (no route)	Number of data packets that could not be forwarded as route to destination was unavailable.
HWMP Data packets dropped (buffer overflow)	Number of data packets that could not be forwarded as buffer limit was exceeded.

4.4.6 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the 802.11s MAC model. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/dot11s. Table 4-61 lists the sub-directory where each scenario is located.

TABLE 4-61. 802.11s MAC Scenarios Included in EXata

Scenario Sub-directory	Description
Hwmp-adhoc	Shows a 6 mesh point rectangular grid which illustrates multi-hop behavior using layer-2 HWMP on-demand/ad-hoc mode routing.
Hwmp-proactive	Shows a mesh scenario configured with a HWMP root MP which facilitates creation of pro-active roots by periodic announcements.
Inter-network	Shows inter-networking between a mesh and wired nodes using Layer 3 connectivity.
Wireless-link	Shows a mesh network as a wireless inter-connect between non-wireless subnetworks.

4.4.7 References

1. Draft Amendment to Standard for Information Technology -Telecommunications and Information Exchange Between Systems -- LAN/MAN Specific Requirements -- Part 11: Wireless Medium Access Control (MAC) and physical layer (PHY) specifications: Amendment: ESS Mesh Networking, IEEE Unapproved draft IEEE P802.11s/D0.02. June 2006.
2. IEEE Std 802.11–1999. "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications." March 18, 1999.
3. Bob O'Hara, Al Petrick.The IEEE 802.11 Handbook: A Designers Companion. United States Of America:Standards Information Network IEEE Press.

4.5 Abstract Network Equation – Satellite (ANESAT) Model

4.5.1 Description

This ANESAT abstract satellite model provides an advanced set of tools that simplifies the modeling of:

- Asymmetric channel models
- Upstream traffic conditioners
- Dynamic upstream bandwidth reservation
- Multiple upstream systems
- Spot-beam satellites

These features are characteristics of many advanced broadband satellite systems being deployed presently.

A system is composed of one or more subnets operating across a bidirectional set of channels. Each subnet has a single downstream (or forward) link and a number of associated upstream links. Each downstream link if operated on a TDMA fashion based on the priority dequeuing from the Network layer. Each subnet has a head-end, which may either be the satellite or a head-end ground station, and zero or more client terminals. The usage of the upstream and downstream channels is completely under the control of the head-end process. Each upstream contains a shared set of data that permit it to be scheduled as a group. This most often happens when two or more subnets on a head-end would like to share a common set of upstream channels. Each transmitter (i.e., node/interface pair connected to a satellite channel) can be optionally instantiated with an ingress traffic conditioner. This traffic conditioner limits the amount of traffic being transmitted from the terminal regardless of the available serialization rate available to that terminal. All terminals, including the head-end, process the packets at the network layer. Additional queuing disciplines may be therefore imposed at the client terminal model. These disciplines include strict priority queuing and weighted fair queuing.

4.5.2 Features and Assumptions

This section describes the implemented features, omitted features, assumptions and limitations of the ANESAT model.

4.5.2.1 Implemented Features

- Both bent-pipe and processing payload functionality.
- An advanced DAMA for the satellite models
- 80x speed up on models
- A high performance scheduler for EXata
- Necessary abstractions for high performance operation in bent-pipe and satellite model

4.5.2.2 Omitted Features

None

4.5.2.3 Assumptions and Limitations

- Abstractions were used in the implementation of this model.

4.5.3 Supplemental Information

None.

4.5.4 Command Line Configuration

To specify ANESAT as the MAC protocol, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   MAC-PROTOCOL                 ANE
```

The scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

ANESAT Parameters

Table 4-62 lists the ANESAT parameters specified in the scenario configuration (.config) file. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 4-62. ANESAT Parameters

Parameter	Value	Description
ANESAT-SATELLITE-ARCHITECTURE *Optional* *Scope:* All	List: • BENTPIPE • PROCESSPAYLOAD *Default:* PROCESSPAYLOAD	Specifies the type of satellite system to be modeled (i.e., sets architecture of subnet to be either switched/routed in space or at the ground station).
ANESAT-UPLINK-CHANNEL *Optional* *Scope:* All	Integer *Range:* ≥ 0 *Default:* 0	Specifies the channel with which this interface address or node is to be associated.
ANESAT-UPSTREAM-GROUP *Optional* *Scope:* All	String *Default:* DefaultUpstreamGroup	Specifies the upstream group for a sharing of upstream resources across multiple subnets. This only has physical realism if the interfaces/subnets are all on one node, like a multi-beam or multi-channel satellite. This parameter is required only if the scenario has more than one ANESAT subnet. Each ANESAT subnet requires a unique upstream group ID.
ANESAT-UPSTREAM-COUNT *Optional* *Scope:* All	Integer *Range:* > 0 *Default:* 1	Specifies the number of total upstreams in the simulation.
ANESAT-UPSTREAM-BANDWIDTH *Optional* *Scope:* All *Instances:* upstream channel index	Real *Range:* > 0 *Default:* 1.0e6 *Unit:* bps	Specifies the upstream bandwidth for a particular upstream channel.

TABLE 4-62. ANESAT Parameters (Continued)

Parameter	Value	Description
ANESAT-UPSTREAM-MAC-LATENCY *Optional* *Scope:* All *Instances:* upstream channel index	Time *Range:* ≥ 0S *Default:* 0.04S	Specifies the upstream media access latency for a particular upstream channel.
ANESAT-DOWNSTREAM-BANDWIDTH *Optional* *Scope:* All	Real *Range:* > 0 *Default:* 70.0e6 *Unit:* bps	Specifies the downstream bandwidth for a particular downstream channel.
ANESAT-DOWNSTREAM-MAC-LATENCY *Optional* *Scope:* All	Time *Range:* ≥ 0S *Default:* 0.005S	Specifies the downstream media access latency for a given downstream channel
ANESAT-UPSTREAM-TRAFFIC-CONDITIONING-TYPE *Optional* *Scope:* All	List: • RESIDUAL • STRICT • NONE *Default:* NONE	Specifies the type of upstream traffic conditioner. RESIDUAL: A residual bandwidth limiting operation is performed. When this type is specified, ANESAT-UPSTREAM-BANDWIDTH-LIMIT and ANESAT-UPSTREAM-BANDWIDTH-MINIMUM parameters must be configured. STRICT: Bandwidth is strictly limited to the value of the traffic limit. When this type is specified, ANESAT-UPSTREAM-BANDWIDTH-LIMIT parameter must be configured. NONE: No conditioning is performed at the ingress interface.
ANESAT-UPSTREAM-BANDWIDTH-MINIMUM *Optional* *Scope:* All	Real *Range:* > 0 *Default:* 64000 *Unit:* bps	Specifies the minimum bandwidth to be allocated by the upstream traffic conditioner. **Note:** This parameter is used for residual conditioning only.

TABLE 4-62. ANESAT Parameters (Continued)

Parameter	Value	Description
`ANESAT-UPSTREAM-BANDWIDTH-LIMIT` *Optional* *Scope:* All	Real *Range:* > `ANESAT-UPSTREAM-BANDWIDTH-MINIMUM` *Default:* `512000` *Unit:* bps	Specifies the bandwidth limit on the upstream traffic conditioner. **Note:** This parameter is used for strict or residual conditioning only.
`ANESAT-CHANNEL-ID` *Required* *Scope:* All	String	Specifies the subnet channel name associated with the node.
`ANE-EQUATION-DEFINITION` *Optional* *Scope:* Subnet	List: • `ane_default_mac` • `anesat_mac` *Default:* `ane_default_mac`	Specifies the name of the equation object (class or shared object). `ane_default_mac`: Base satellite `anesat_mac`: Multichannel satellite
`ANE-SUBNET-ARCHITECTURE` *Optional* *Scope:* Subnet	List: • `ASYMMETRIC` • `SYMMETRIC` *Default:* `SYMMETRIC`	Specifies the subnet topology. `ASYMMETRIC`: This value indicates a client/server architecture where the topology would be configured as “Host to Gateway”. If asymmetric host style is specified, `ANE-HEADEND-NODE` parameter must also be configured. `SYMMETRIC`: Subnet architecture is “Host to Host”.
`ANE-HEADEND-NODE` *Optional* *Scope:* Subnet	Integer *Range:* > `0`	Specifies the node that is the master of the subnet transmissions, both upstream and downstream. **Note:** This parameter is required only for asymmetric architecture.
`ANE-PROCESSOR-NODE` *Required* *Scope:* Subnet	Integer *Range:* > `0`	Specifies the centralized processor node for Distributed Memory Architecture (DMA) or cluster instantiation. **Note:** This is a required parameter for centralized processor.

TABLE 4-62. ANESAT Parameters (Continued)

Parameter	Value	Description
ANE-PROCESSOR-NODE-INDEX *Required* *Scope:* Subnet	Integer *Range:* > 0	Specifies the centralized processor interface index for DMA or cluster instantiation.
GESTALT-PREFER-SHARED-MEMORY *Optional* *Scope:* Global	List: • YES • NO *Default:* YES	This parameter indicates that the simulation should use shared memory optimizations when possible. The ANESAT model uses shared memory optimizations to reduce the simulation overhead while preserving high fidelity operation. **Note:** This option is not available in a cluster environment.

4.5.5 GUI Configuration

This section describes how to configure ANESAT model in the GUI.

Satellite and Ground Station Devices

In the GUI, ANESAT is modeled by the ANE Satellite subnet in the Network Components toolbar of the Standard Toolset.

FIGURE 4-39. ANE Satellite Device in Network Components Toolbar

Ground stations can be modeled by the Default Device or the Ground Station Device in the Devices toolbar of the Standard Toolset.

FIGURE 4-40. Ground Station Device in Devices Toolbar

Configuring ANESAT Parameters

To configure the ANESAT parameters, perform the following steps:

1. Place an ANE Satellite subnet and a Ground Station node on the canvas.
2. Add a link between the ANE Satellite subnet and the Ground Station node.
3. Go to one of the following locations:
   - To set properties for a specific subnet, go to **Wireless Subnet Properties Editor > MAC Layer**.

- To set properties a specific interface of a node, go to one of the following locations:
  - **Interface Properties Editor > Interfaces > Interface # > MAC Layer**.
  - **Default Device Properties Editor > Interfaces > Interface # > MAC Layer**.

In this section, we show how to configure the ANESAT general parameters in the Wireless Subnet Properties editor. Parameters can be set in the other properties editors in a similar way.

4. Set **MAC Protocol** to *Abstract Network Equation (ANE) Satellite* and set the dependent parameters listed in Table 4-63.

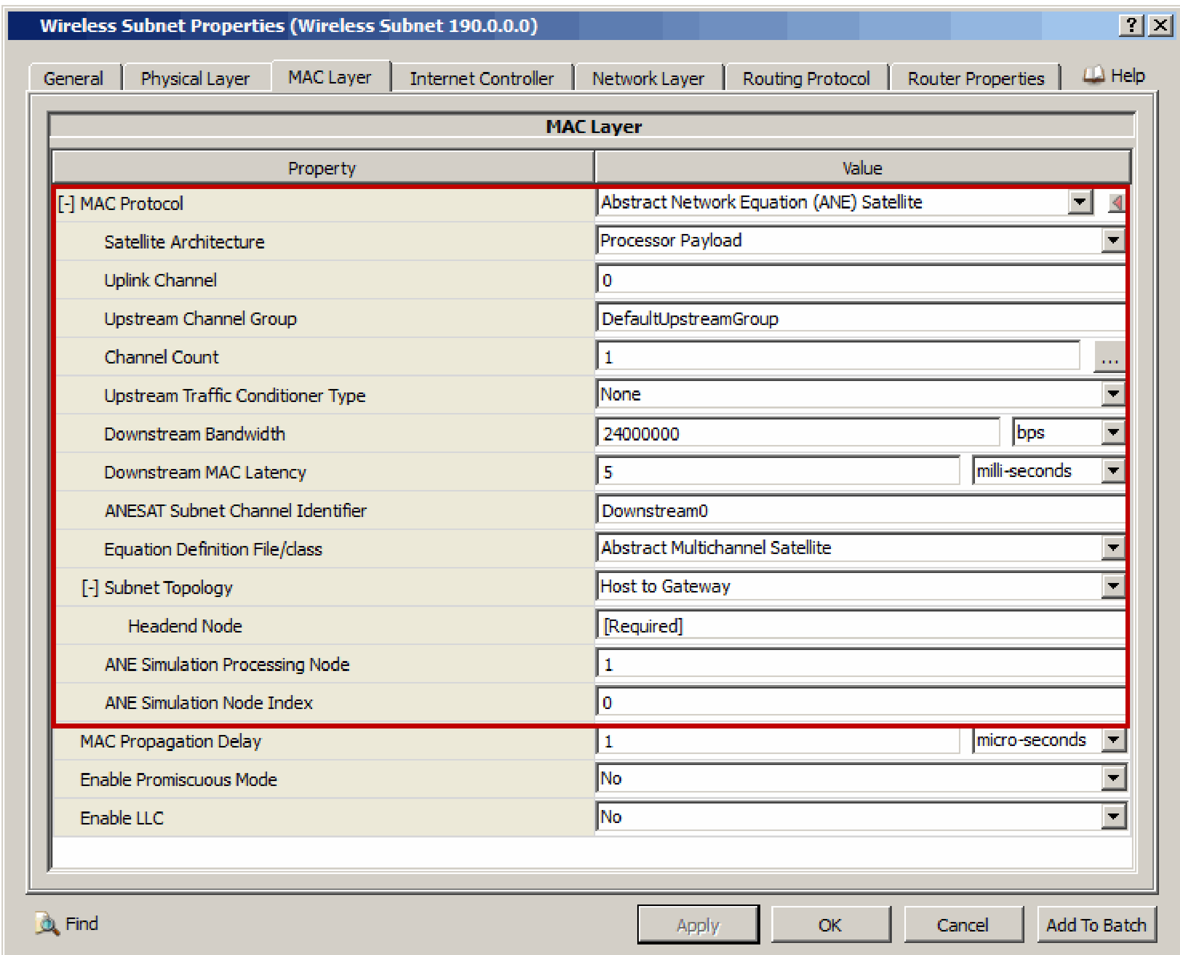


FIGURE 4-41. Setting ANESAT Parameters

TABLE 4-63. Command Line Equivalent of ANESAT Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Satellite Architecture	Subnet, Interface	`ANESAT-SATELLITE-ARCHITECTURE`
Uplink Channel	Subnet, Interface	`ANESAT-UPLINK-CHANNEL`
Upstream Channel Group	Subnet, Interface	`ANESAT-UPSTREAM-GROUP`
Channel Count	Subnet, Interface	`ANESAT-UPSTREAM-COUNT`
Upstream Traffic Conditioner Type	Subnet, Interface	`ANESAT-UPSTREAM-TRAFFIC-CONDITIONING-TYPE`
Downstream Bandwidth	Subnet, Interface	`ANESAT-DOWNSTREAM-BANDWIDTH`
Downstream MAC Latency	Subnet, Interface	`ANESAT-DOWNSTREAM-MAC-LATENCY`
ANESAT Subnet Channel Identifier	Subnet, Interface	`ANESAT-CHANNEL-ID`
Equation Definition File/class	Subnet	`ANE-EQUATION-DEFINITION`
Subnet Topology	Subnet	`ANE-SUBNET-ARCHITECTURE`
ANE Simulation Processing Node	Subnet	`ANE-PROCESSOR-NODE`
ANE Simulation Node Index	Subnet	`ANE-PROCESSOR-NODE-INDEX`

Setting Parameters

- Set **ANE Simulation Processing Node** to the node ID of the Ground Station in the scenario.

5. Set **Channel Count** to the number of upstreams in the scenario and configure the channel properties as follows:

a. Click the **Open Array Editor** button in the **Value** column. This opens the Array Editor (see Figure 4-42).

b. In the left panel of the Array Editor, select the index of the channel to be configured. In the right panel, set the parameters listed in Table 4-64.

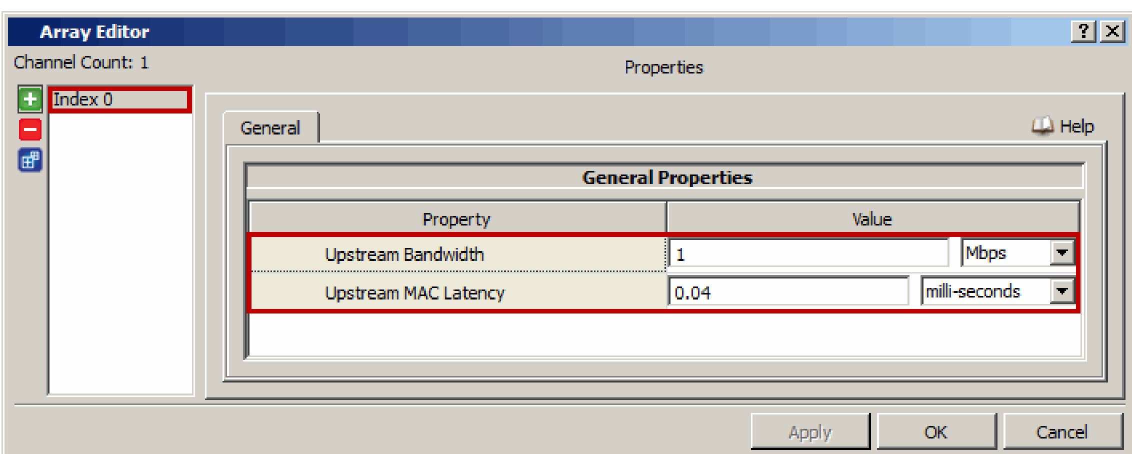


FIGURE 4-42. Setting Upstream Channel Parameters

TABLE 4-64. Command Line Equivalent of Upstream Channel Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Upstream Bandwidth	Subnet, Interface	`ANESAT-UPSTREAM-BANDWIDTH`
Upstream MAC Latency	Subnet, Interface	`ANESAT-UPSTREAM-MAC-LATENCY`

6. If **Upstream Traffic Conditioner Type** is set to *Residual* then set the dependent parameters listed in Table 4-65.

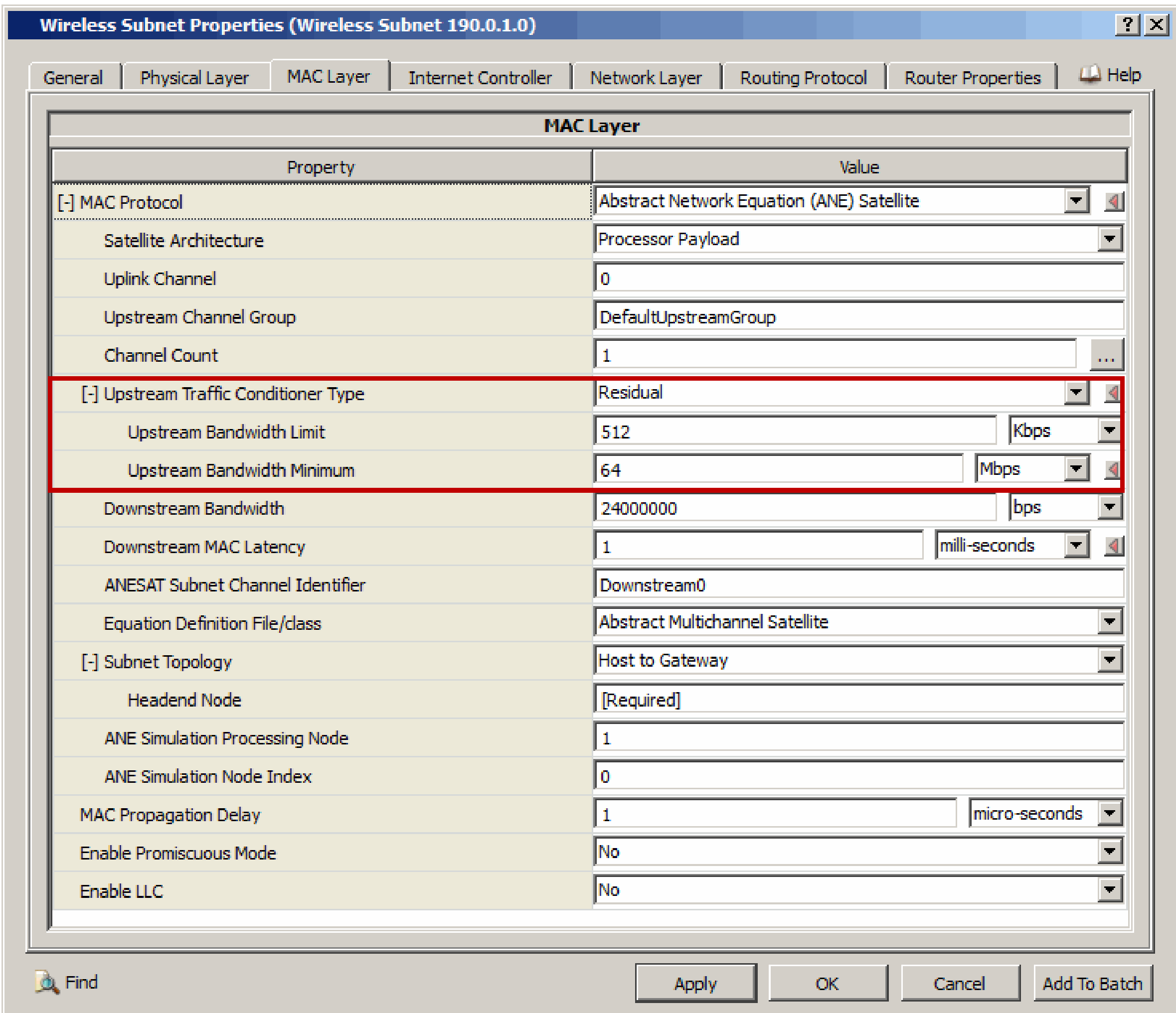


FIGURE 4-43. Setting Parameters for Residual Upstream Traffic Conditioner

TABLE 4-65. Command Line Equivalent of Residual Upstream Traffic Conditioner Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Upstream Bandwidth Limit	Subnet, Interface	ANESAT-UPSTREAM-BANDWIDTH-LIMIT
Upstream Bandwidth Minimum	Subnet, Interface	ANESAT-UPSTREAM-BANDWIDTH-MINIMUM

7. If **Upstream Traffic Conditioner Type** is set to *Strict* then set the dependent parameters listed in Table 4-66.

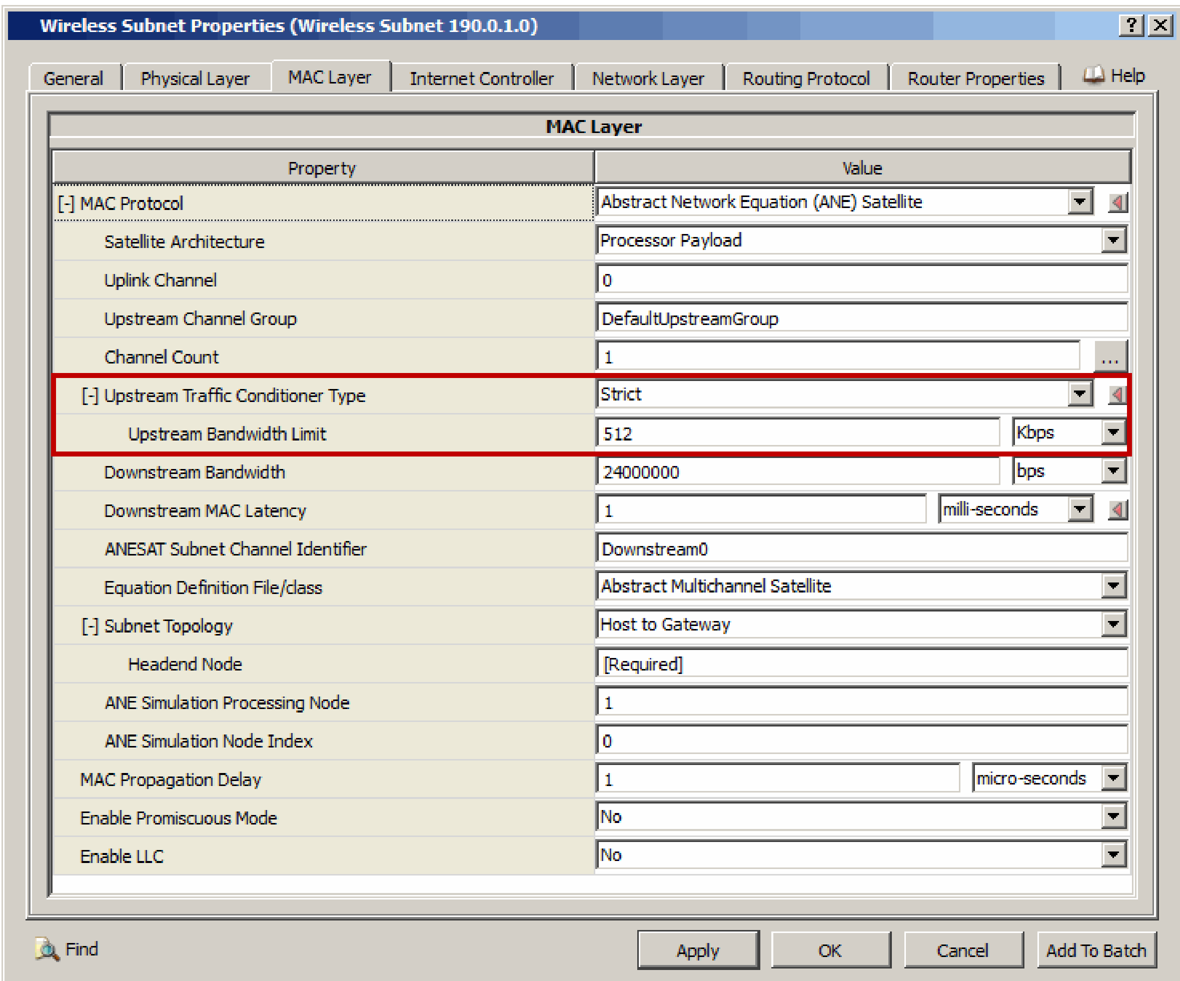


FIGURE 4-44. Setting Parameters for Strict Upstream Traffic Conditioner

TABLE 4-66. Command Line Equivalent of Strict Upstream Traffic Conditioner Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Upstream Bandwidth Limit	Subnet, Interface	`ANESAT-UPSTREAM-BANDWIDTH-LIMIT`

8. If **Subnet Topology** is set to *Host to Gateway* then set the dependent parameters listed in Table 4-67.

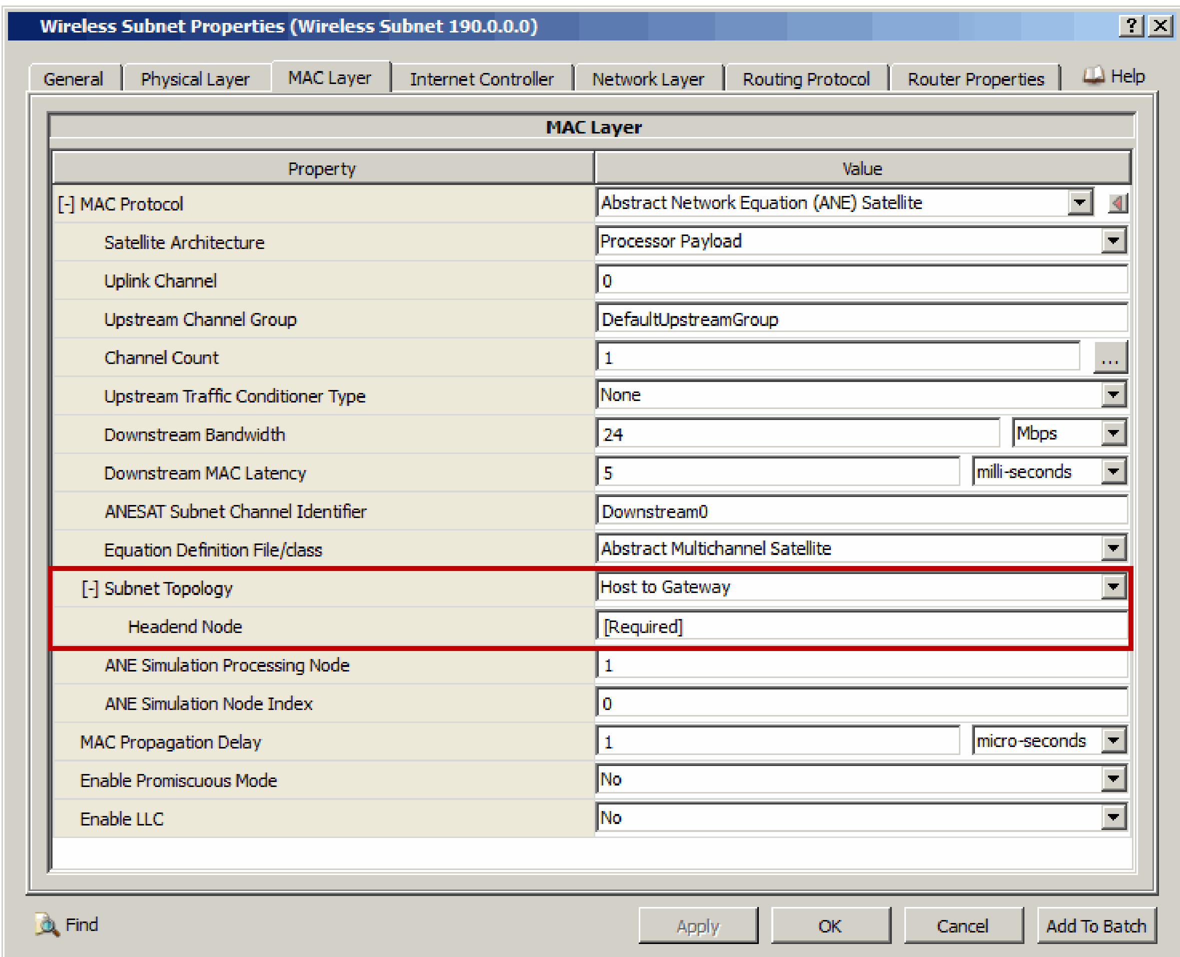


FIGURE 4-45. Setting Subnet Topology Parameters

TABLE 4-67. Command Line Equivalent of Subnet Topology Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Headend Node	Subnet	`ANE-HEADEND-NODE`

Setting Parameters

- Set **Headend Node** to the node ID of the Ground Station in the scenario.

Configuring Memory Optimization Parameters

To configure the memory optimization parameters, perform the following steps:

1. Go to **Scenario Properties Editor > General > Parallel Settings**.
2. To enable shared memory optimizations, set **Prefer Shared Memory** to *Yes*.

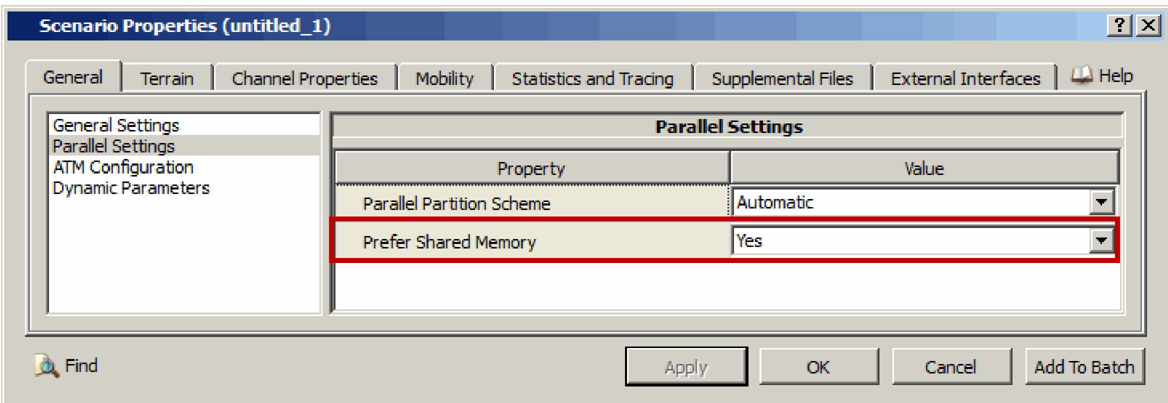


FIGURE 4-46. Setting Memory Optimization Parameters

TABLE 4-68. Command Line Equivalent of Subnet Topology Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Prefer Shared memory	Global	`GESTALT-PREFER-SHARED-MEMORY`

4.5.6 Programming Interface

The model has a single programmatic interface available to the user to modify the dynamic rate limit on the local node's upstream traffic conditioner(s). This is done via the routine MAC_ManagementRequest().

```
void MAC_ManagementRequest(Node *node, int interfaceIndex,
ManagementRequest *req, ManagementResponse *resp);
```

The MAC responds to the following request types:

- ManagementRequestEcho: A basic ping to check process is still working
- ManagementRequestSetBandwidthLimit: The STRICT traffic conditioner accepts this command and updates its local traffic conditioning rate limit. The new limit is passed to the process as a pointer to a double that contains the new rate limit. That pointer is to be stored in req > data.

If supported, the MAC responds with ManagementResponseOK. More details can be found on the data structures in mac/mac.h. An example of the use of MAC_ManagementRequest is shown below:

```
void setbw(Node *node, int ifidx) {
    ManagementRequest req, resp;
    double updatedBandwidth = 768.0e3;

    req.type = ManagementRequestSetBandwidthLimit;
    req.data = (void*)&updatedBandwidth;

    MAC_ManagementRequest(node, ifidx, &req, &resp);

    if (resp.result != ManagementResponseOK) {
         // error
    }
}
```

4.5.7 Statistics

Table 4-69 lists the statistics collected for the ANESAT model that are output to the statistics (.stat) file at the end of simulation.

TABLE 4-69. ANESAT Statistics

Statistic	Description
Frames sent	Total number of frames sent
Frames received	Total number of frames received
Frames relayed	Total number of frames relayed

4.5.8 Sample Scenario

4.5.8.1 Scenario Description

Topology

The sample scenario topology is shown in Figure 4-47.

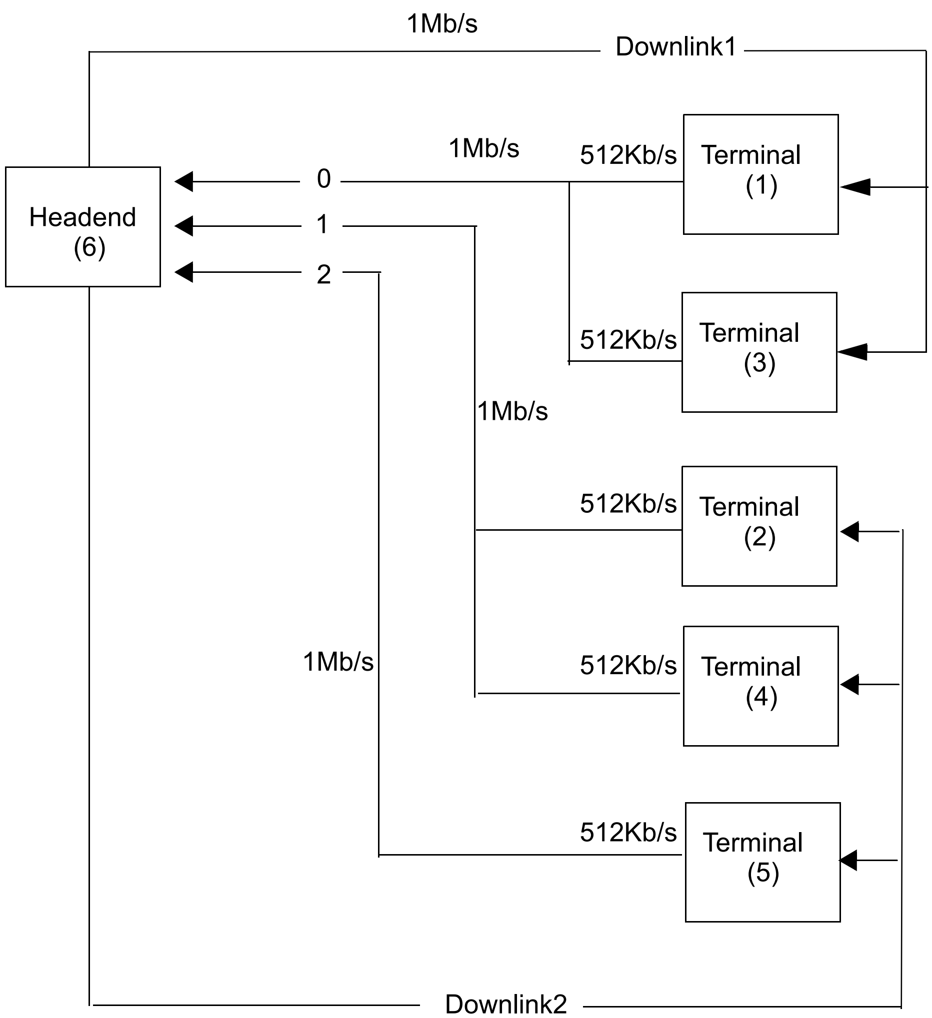


FIGURE 4-47. Sample Scenario Topology

4.5.8.2 Command Line Configuration

To configure the sample scenario, include the following lines in the scenario configuration (.config) file:

```
APP-CONFIG-FILE ./ane-example.app

SUBNET N8-0.0 { 1,3,6 }
[N8-0.0] ANESAT-CHANNEL-ID Downlink1
[N8-0.0] ANE-HEADEND-NODE 6
#
SUBNET N8-1.0 { 2,4,5,6 }
[N8-1.0] ANESAT-CHANNEL-ID Downlink2
[N8-1.0] ANE-HEADEND-NODE 6
#
[1] ANESAT-UPLINK-CHANNEL 0
[2] ANESAT-UPLINK-CHANNEL 1
[3] ANESAT-UPLINK-CHANNEL 0
[4] ANESAT-UPLINK-CHANNEL 1
[5] ANESAT-UPLINK-CHANNEL 2
#
MAC-PROTOCOL   ANE
ANE-EQUATION-DEFINITION anesat_mac
ANE-SUBNET-ARCHITECTURE Asymmetric
ANESAT-SATELLITE-ARCHITECTURE BentPipe
ANESAT-UPSTREAM-TRAFFIC-CONDITIONING-TYPE RESIDUAL

ANESAT-UPSTREAM-COUNT 3

ANESAT-UPSTREAM-BANDWIDTH 1.0e6
ANESAT-DOWNSTREAM-BANDWIDTH 1.0e6

ANESAT-UPSTREAM-BANDWIDTH-LIMIT 512.0e3
ANESAT-UPSTREAM-BANDWIDTH-MINIMUM 64.0e3

ANESAT-UPSTREAM-MAC-LATENCY 0.001
ANESAT-DOWNSTREAM-MAC-LATENCY 0.001
```

Include the following lines in the application configuration (ane-example.app) file:

```
CBR 5 2 0 512 10MS 100S 400S PRECEDENCE 0
CBR 1 2 0 512 10MS 100S 400S PRECEDENCE 1
CBR 4 2 0 512 10MS 100S 400S PRECEDENCE 2
```

4.5.8.3 GUI Configuration

The following scenario is designed using the QualNet GUI. To create a new scenario perform the following steps:

1. Place six **Ground Station**  devices and two **ANE Satellite Subnets** . Connect them with links as shown in Figure 4-48.

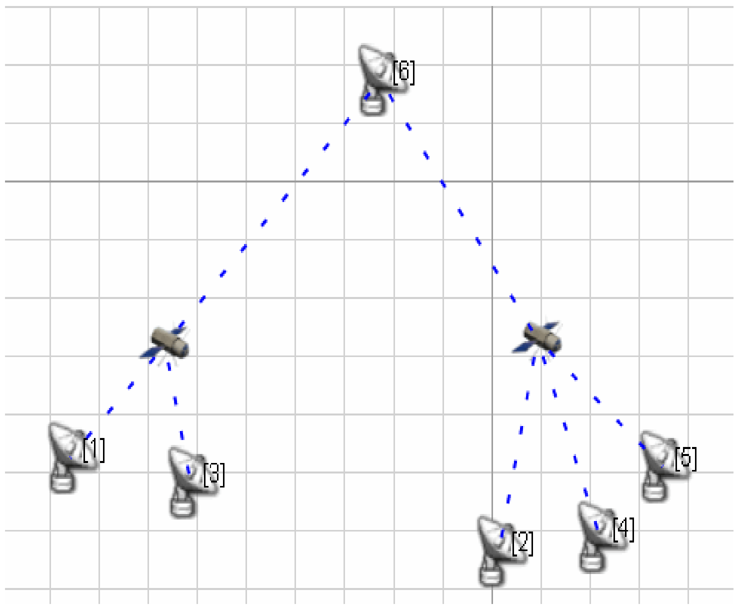


FIGURE 4-48. Sample Scenario GUI Layout

2. For subnet 190.0.1.0 (left satellite), go to **Wireless Subnet Properties Editor > MAC Layer** and set the properties as shown in Figure 4-49**.**

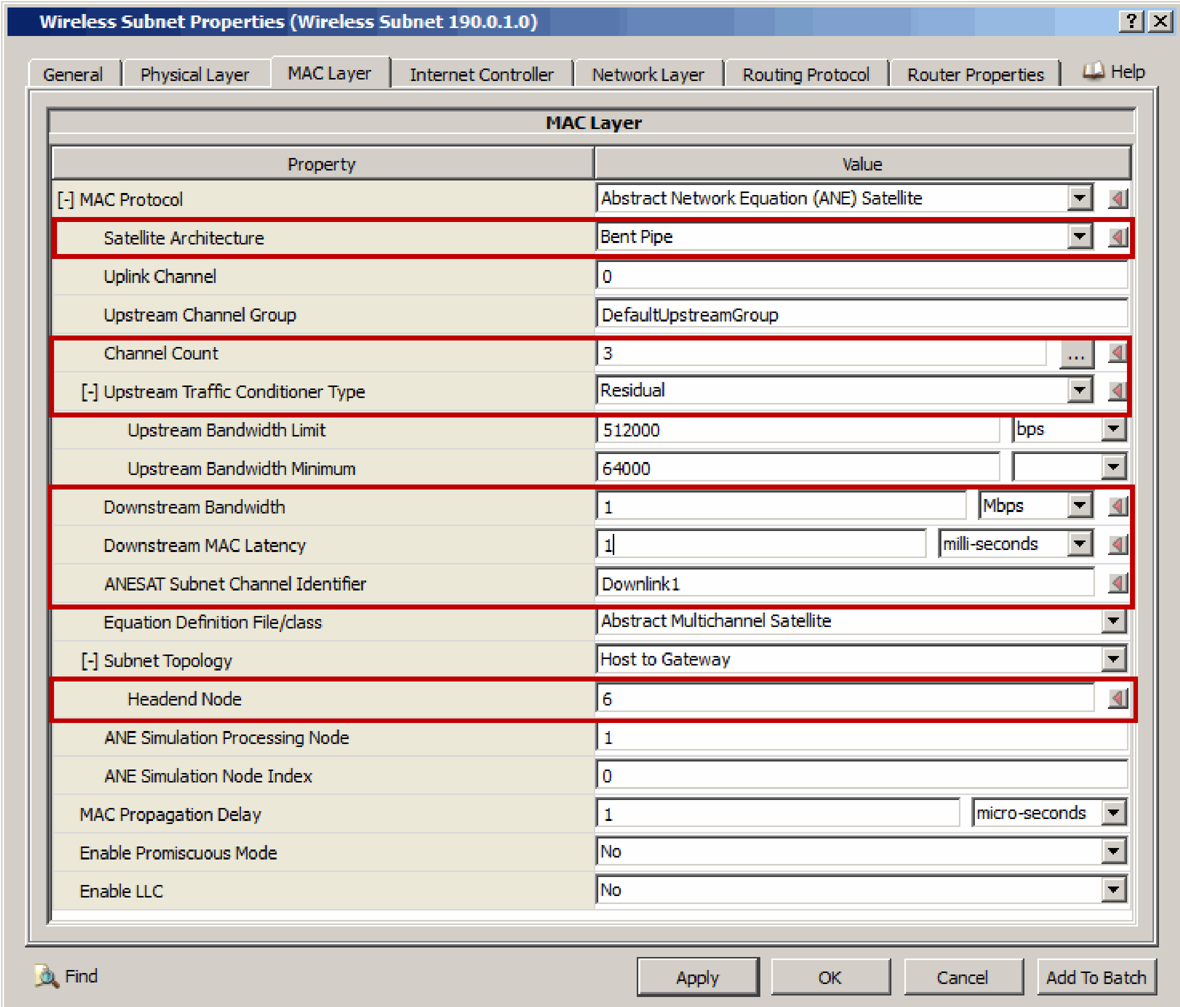


FIGURE 4-49. Left Satellite Properties

3. To set the uplink channel parameters, open the array editor for the **Channel Count** parameter and set the properties as shown in Figure 4-50 for each of the indices.

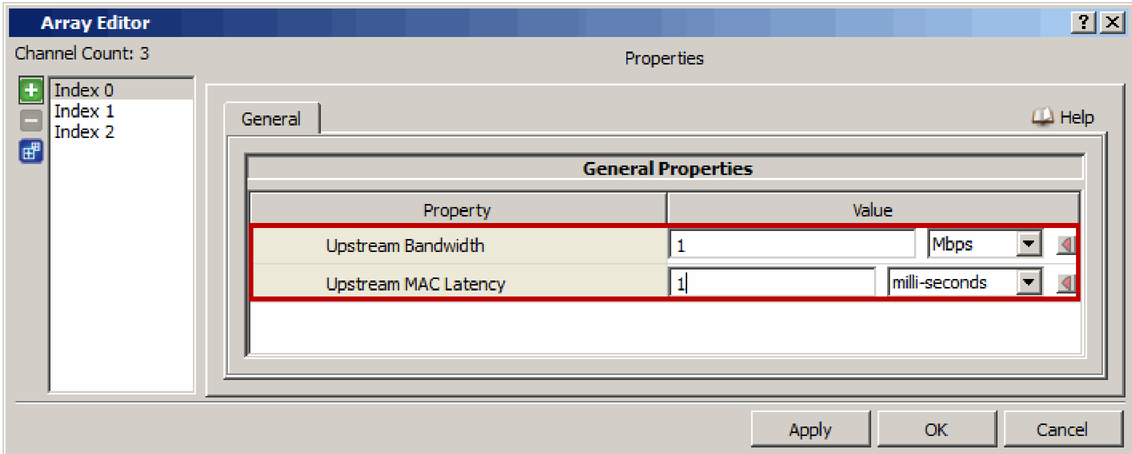


FIGURE 4-50. Upstream Channel Properties

4. For subnet 190.0.2.0 (right satellite), set the properties as shown in Figure 4-49 and Figure 4-50, except for setting **ANESAT Subnet Channel Identifier** to *Downlink2*.
5. For node 1 (Ground Station 1):
   - Go to **Default Device Properties Editor > Interfaces > Interface 0 > MAC Layer**.
   - Set **MAC Protocol** to *Abstract Network Equation (ANE) Satellite.*
   - Set **Satellite Architecture** to *Bent Pipe.*
   - Se **Uplink Channel** to *0*.

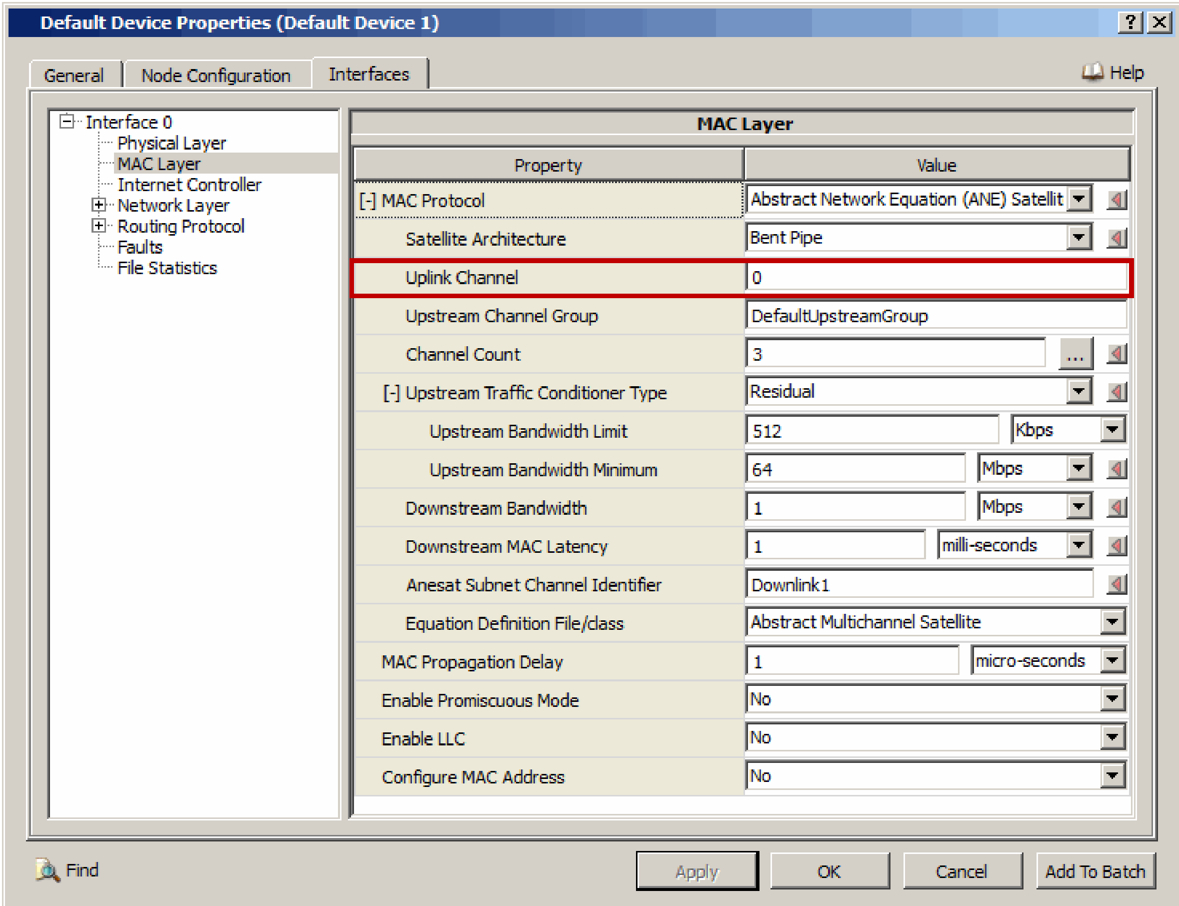


FIGURE 4-51. Uplink Channel for Ground Station 1

6. Similarly, set **Uplink Channel** to *1*, *0*, *1*, and *2* for nodes 2, 3, 4 and 5, respectively.

7. Add CBR applications between the following nodes: 5 to 2, 1 to 2, and 4 to 2.
8. For the CBR application between nodes 5 and 2, set the **Precedence Value** to *0*, between nodes 1 and 2 set the **Precedence Value** to *1*, and between nodes 4 and 2 set the **Precedence Value** to *2*.

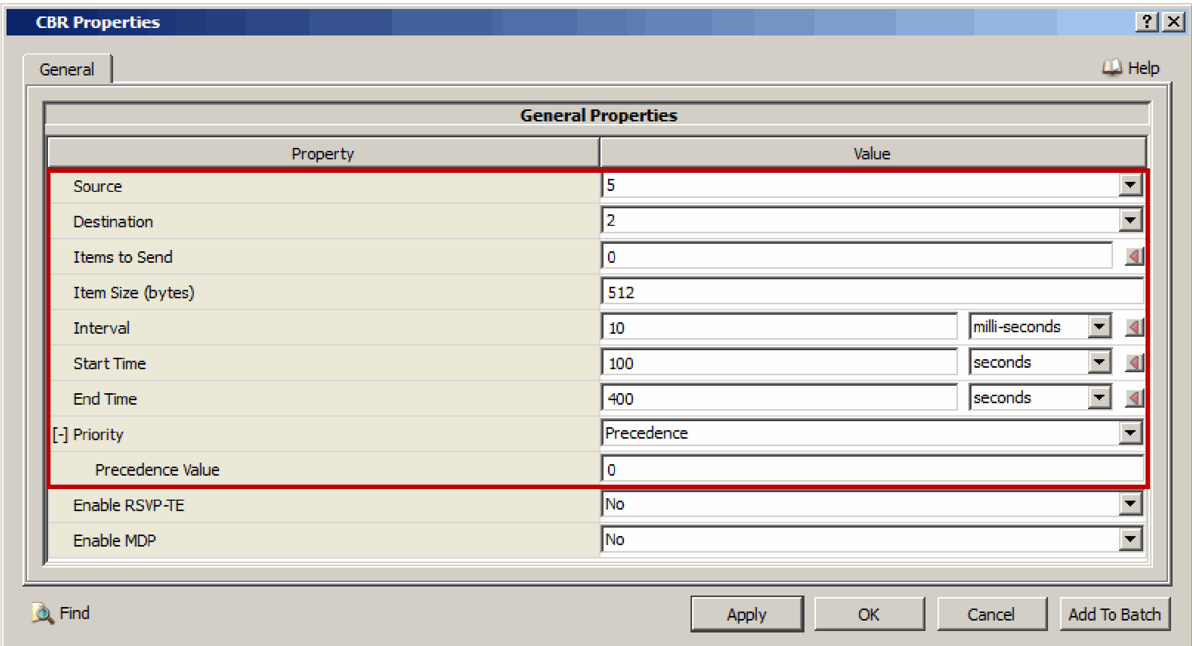


FIGURE 4-52. Sample CBR Configuration Settings

4.5.9 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the ANESAT model. All scenarios are located in the directory EXATA_HOME/scenarios/satellite/ane. Table 4-70 lists the sub-directory where each scenario is located.

TABLE 4-70. ANESAT Model Scenarios

Scenario Sub-directory	Description
centralized	Shows the example of ANE centralized scheduling methods.
distributed	Shows the example of ANE distributed scheduling methods.
two-sat	Shows the example of simultaneous ANE operation.

4.6 Aloha MAC Protocol

4.6.1 Description

Aloha is a wireless random access MAC protocol that transmits data whenever there is data to send (no carrier sensing). If no acknowledgement is received, the source retransmits at a later time.

4.6.2 Command Line Configuration

To specify Aloha as the MAC protocol, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   MAC-PROTOCOL         ALOHA
```

The scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

Aloha Parameters

Table 4-71 lists the Aloha parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 4-71. Aloha Parameters

Parameter	Value	Description
`MAC-LAYER-STATISTICS` *Optional* *Scope:* All	List: • `YES` • `NO` Default: `NO`	Indicates whether statistics are collected for MAC protocols, including Aloha.

4.6.3 GUI Configuration

This section describes how to configure Aloha MAC Protocol in the GUI.

Configuring Aloha MAC Protocol Parameters

To configure the Aloha MAC Protocol parameters, perform the following steps:

1. Go to one of the following locations:
   - To set wireless subnet properties, go to wireless subnet **Properties Editor > MAC Layer**.
   - To set properties for a specific interface of a node, go to **Node Interfaces Properties Editor > Interfaces > Interface # > MAC Layer**.

   In this section, we show how to configure Aloha MAC Protocol parameters for a specific interface using the Default Device Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **MAC Protocol** to *Aloha*. There are no dependent parameters for this model.

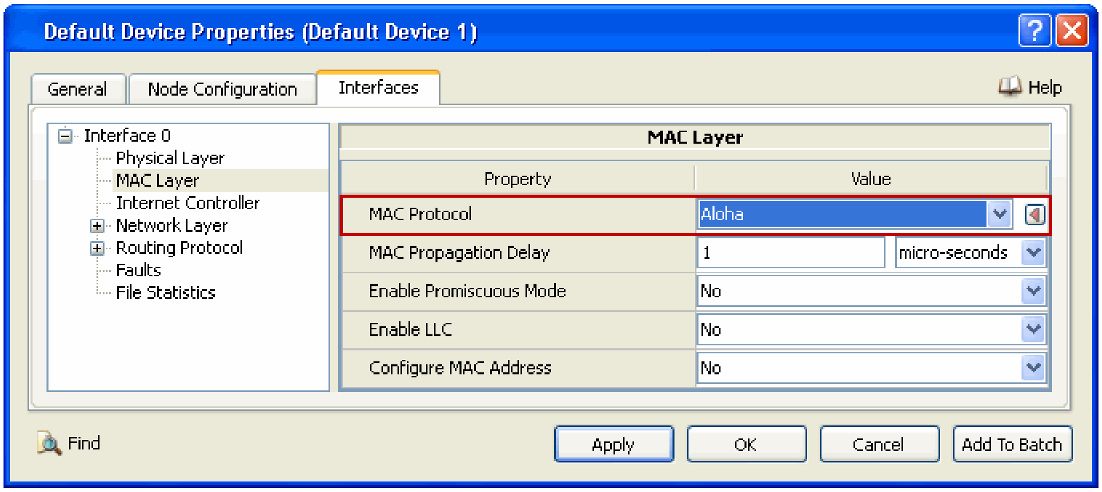


FIGURE 4-53. Setting MAC Protocol to Aloha

Configuring Statistics Parameters

Statistics for Aloha MAC Protocol can be collected at the global, node, subnet, and interface levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for Aloha MAC, check the box labeled MAC in the appropriate properties editor.

TABLE 4-72. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
MAC	Global, Node, Subnet, Interface	`MAC-LAYER-STATISTICS`

4.6.4 Statistics

This section describes the file and dynamic statistics of the Aloha model.

4.6.4.1 File Statistics

Table 4-73 shows the Aloha statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 4-73. Aloha Statistics

Statistic	Description
Packets Sent to Channel	Number of data packets sent to channel
Packets Received from Channel	Number of data packets received from channel
Packets Dropped	Number of data packets dropped

4.6.4.2 Dynamic Statistics

The following dynamic statistics are enabled for the Aloha model (refer to Chapter 6 of *EXata User's Guide* for details of viewing dynamic statistics in the GUI during the simulation):

- Number of Packets Sent
- Number of Packets Received
- Number of Packets Dropped

4.7 Carrier Sense Multiple Access (CSMA) MAC Protocol

4.7.1 Description

Carrier Sense Multiple Access (CSMA) is a generic carrier-sensing protocol. When a radio wishes to send data, it senses the channel. If the channel is busy, it backs off for a random time period before sensing the channel again. If the channel is free, the radio transmits the packet.

4.7.2 Command Line Configuration

To specify CSMA as the MAC protocol, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   MAC-PROTOCOL         CSMA
```

The scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

CSMA Parameters

Table 4-74 lists the CSMA parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 4-74. CSMA Parameter

Parameter	Value	Description
`MAC-LAYER-STATISTICS` *Optional* *Scope:* All	List • `Yes` • `NO` *Default:* `NO`	Indicates whether statistics are collected for MAC layer protocols, including CSMA.

4.7.3 GUI Configuration

This section describes how to configure CSMA MAC Protocol in the GUI.

Configuring CSMA MAC Protocol Parameters

To configure CSMA MAC Protocol parameters, perform the following steps:

1. Go to one of the following locations:

- To set wireless subnet properties, go to **Wireless Subnet Properties Editor > MAC Layer**.
- To set properties for a specific interface of a node, go to **Node Interfaces Properties Editor > Interface # > MAC Layer**.

In this section, we show how to configure CSMA MAC Protocol parameters for a specific interface using the Default Device Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **MAC Protocol** to *CSMA*. There are no dependent parameters for this MAC Protocol.

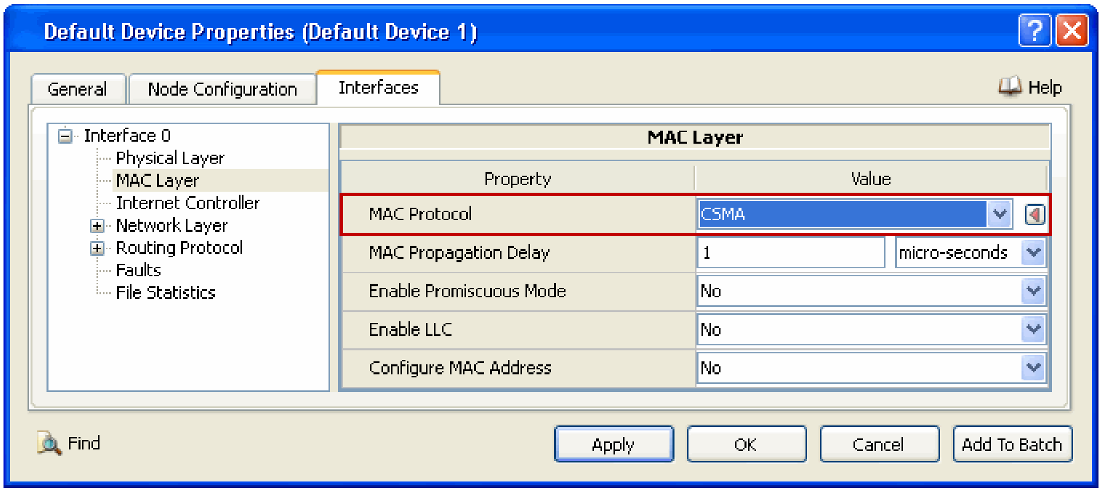


FIGURE 4-54. Setting MAC Protocol to CSMA

Configuring Statistics Parameters

Statistics for the CSMA MAC model can be collected at the global, node, subnet, and interface levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for CSMA, check the box labeled **MAC** in the appropriate properties editor.

TABLE 4-75. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
MAC	Global, Node, Subnet, Interface	`MAC-LAYER-STATISTICS`

4.7.4 Statistics

Table 4-76 shows the CSMA statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 4-76. CSMA Statistics Collected

Statistic	Description
Packets from network	Packets received from Network Layer Protocol, i.e. IP
Packets lost to buffer overflow	Packets dropped at the MAC layer due to buffer overflow
Unicast packets sent to channel	Packets with a specific destination address transmitted on the channel
Broadcast packets sent to channel	Packets broadcast to all radios within transmission range
Unicast packets received	Packets destined for this specific radio and successfully received
Broadcast packets received	Packets destined for all radios and successfully received by this radio

4.8 Generic MAC Protocol

4.8.1 Description

The Generic MAC protocol is a configurable MAC model that allows you to choose the protocol's channel access, RTS/CTS, and ACK capabilities of the protocol. The model implements several channel access policies, which are described below:

Packet Sense Multiple Access (PSMA)

Channel availability is not checked before sending out data on the channel.

Carrier Sense Multiple Access (CSMA)

In this policy, the node senses the channel before sending data. If the channel is idle, data is sent immediately; otherwise, the node starts a backoff timer. When the backoff timer expires, the node senses the channel again. If the channel is idle, data is sent immediately; otherwise, the node restarts the backoff timer. This is repeated until the data is successfully transmitted or the maximum number of retransmissions is reached. The backoff time is randomly selected from a time interval which increases exponentially with each retransmission attempt. If the maximum number of retransmissions are reached, the packet is dropped.

Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA)

This policy is similar to CSMA with the exception that the backoff timer is paused when a channel becomes busy. The backoff timer is resumed when the channel becomes idle again. The backoff timer works during the collision avoidance period, and data is transmitted on the channel during other periods.

Slotted CSMA

In slotted CSMA, the time line is divided into equal slots. This policy is similar to CSMA except that a node can attempt to transmit only at the beginning of a slot. At the start of a new time slot, channel sensing is done. If the channel is found to be idle, the node sends data on the channel. If channel is busy, the data is rescheduled to some randomly chosen time in the future using the backoff timer.

Slotted CSMA with Collision Avoidance

This policy is similar to CSMA-CA, except that the slots are pre-determined based on the backoff timers. If the node wants to transmit data, it senses the channel randomly using the backoff timer within a collision avoidance period before transmitting the packet to verify a clear channel.

4.8.2 Command Line Configuration

To specify Generic MAC as the MAC protocol, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   MAC-PROTOCOL         GENERICMAC
```

The scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

Generic MAC Parameters

Table 4-77 lists the Generic MAC parameters specified in the scenario configuration (.config) file. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 4-77. Generic MAC Parameters

Parameter	Value	Description
CHANNEL-ACCESS *Optional* *Scope:* All	List: • PSMA • CSMA • CSMA-CA • SLOT-CSMA • SLOT-CSMA-CA *Default:* PSMA	Specifies the policy used to access the channel. PSMA : Packet Sense Multiple Access CSMA : Carrier Sense Multiple Access CSMA-CA : CSMA with Collision Avoidance SLOT-CSMA : Slotted CSMA SLOT-CSMA-CA: Slotted CSMA with Collision Avoidance
RTS-CTS *Optional* *Scope:* All	List: • YES • NO *Default:* NO	Enables the RTS-CTS transmission before sending a unicast frame.
ACK *Optional* *Scope:* All	List: • YES • NO *Default:* NO	Enables the acknowledgement of frame sent.
RETRY-LIMIT *Optional* *Scope:* All *Instances:* No	Integer *Range:* ≥ 0 *Default:* 25	Specifies the retry limit of the frame before the frame is dropped.
SLOT *Optional* *Scope:* All	Time *Range:* > 0S *Default:* 10MS	Specifies the time duration of each slot. This duration should be long enough for a packet to be transmitted. This parameter is used if CHANNEL-ACCESS is set to SLOT-CSMA or SLOT-CSMA-CA.
MAC-LAYER-STATISTICS *Optional* *Scope:* All	List • Yes • NO *Default:* NO	Indicates whether statistics are collected for MAC layer protocols, including Generic MAC.

4.8.3 GUI Configuration

This section describes how to configure Generic MAC Protocol in the GUI.

Configuring Generic MAC Protocol Parameters

To configure the Generic MAC Protocol parameters, perform the following steps:

1. Go to one of the following locations:
   - To set wireless subnet properties, go to **Wireless Subnet Properties Editor > MAC Layer**.
   - To set properties for a specific interface of a node, go to **Node Interfaces Properties Editor > Interface # > MAC Layer**.

   In this section, we show how to configure Generic MAC Protocol parameters for a specific interface using the Default Device Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **MAC Protocol** to *Generic MAC* and set the dependent parameters listed in Table 4-78.

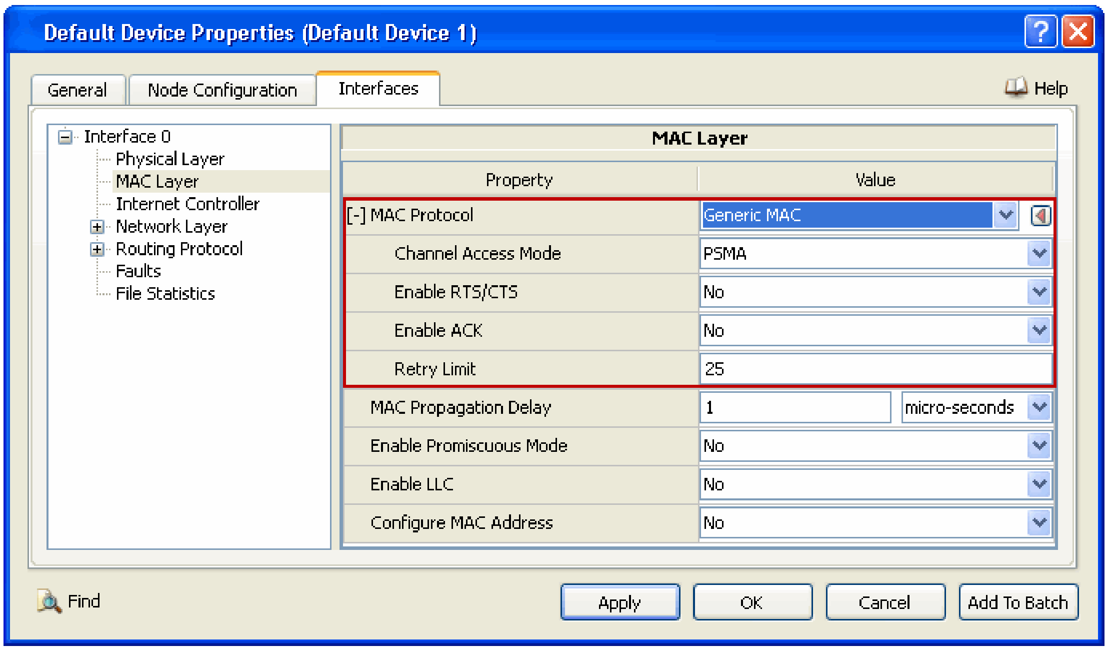


FIGURE 4-55. Setting Generic MAC Parameters

TABLE 4-78. Command Line Equivalent of Generic MAC Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Channel Access Mode	Node, Subnet, Interface	`CHANNEL-ACCESS`
Enable RTS/CTS	Node, Subnet, Interface	`RTS-CTS`
Enable ACK	Node, Subnet, Interface	`ACK`
Retry Limit	Node, Subnet, Interface	`RETRY-LIMIT`

Setting Parameters

- Set Channel Access Mode from the list (*CSMA, CSMA-CA, PSMA, SLOT-CSMA, SLOT-CSMA-CA*)
- To set RTS/CTS, set **Enable RTS/CTS** to *Yes*; otherwise, set **Enable RTS/CTS** to *No*.

- To enable ACK, set **Enable ACK** to *Yes*; otherwise, set **Enable ACK** to *No*.

3. If **Channel Access Mode** is set to *SLOT-CSMA* or *SLOT-CSMA-CA*, specify slot duration as shown in Figure 4-56. For other options there are no dependent parameters.

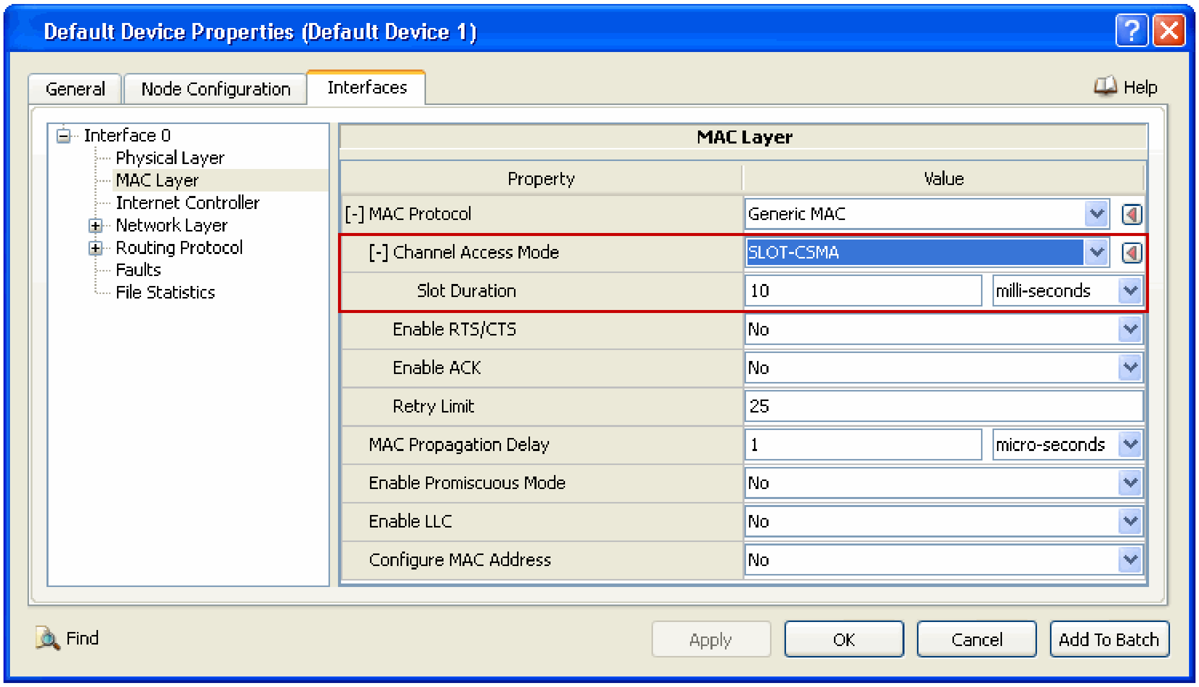


FIGURE 4-56. Setting Slot Duration

TABLE 4-79. Command Line Equivalent of Channel Access Mode Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Slot Duration	Subnet, Interface	`SLOT`

Configuring Statistics Parameters

Statistics for the Generic MAC model can be collected at the global, node, subnet, and interface levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for Generic MAC, check the box labeled **MAC** in the appropriate properties editor.

TABLE 4-80. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
MAC	Global, Node, Subnet, Interface	`MAC-LAYER-STATISTICS`

4.8.4 Statistics

Table 4-81 shows the Generic MAC statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 4-81. Generic MAC Statistics

Statistic	Description
Packets from network	Number of data packets passed from upper layer.
Packets lost	Number of data packets dropped due to retry time out.

4.9 Microwave Links

4.9.1 Description

Microwave links are implemented as an extension of point-to-point links. They represent connections between microwave towers. Microwave links can have errors and can be affected by weather and other factors. They do not interfere with other transmissions.

4.9.2 Command Line Configuration

To specify Microwave as the PHY model, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   LINK-PHY-TYPE        MICROWAVE
```

The scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

Microwave Link Parameters

Table 4-82 describes the Microwave Link configuration parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 4-82. Microwave Link Parameters

Parameter	Value	Description
`LINK-PROPAGATION-SPEED` *Optional* *Scope:* Global *Instances:* channel index	Real *Range:* `> 0.0` *Default:* `3.0e8` *Unit:* meters/sec	Signal propagation speed.
`LINK-BANDWIDTH` *Required* *Scope:* All	Integer *Range:* `> 0` *Unit:* bps	Specifies the bandwidth of the link.
`LINK-HEADER-SIZE-IN-BITS` *Optional* *Scope:* All	Integer *Range:* `> 0` *Default:* `224` *Unit:* bits	Specifies the header size.

TABLE 4-82. Microwave Link Parameters

Parameter	Value	Description
LINK-GENERATE-AUTOMATIC-DEFAULT-ROUTE *Optional* *Scope:* All	List: • YES • NO *Default:* YES	Enables the automatic generation and population of a default route between the two end-points of the link in the IP forwarding table. If this parameter is set to YES, the two end-points of a link will be able to route packets to each other without any further configuration. If this parameter is set to NO, other measures must be taken to ensure that packets can be routed between the two connected nodes.
LINK-TX-FREQUENCY *Required* *Scope:* All	Real *Range:* > 0.0 *Unit:* Hz	Specifies the transmit frequency.
LINK-RX-FREQUENCY *Required* *Scope:* All	Real *Range:* > 0.0 *Unit:* Hz	This parameter is used to specify receive frequency.
LINK-TX-ANTENNA-HEIGHT *Optional* *Scope:* All	Real *Range:* > 0.0 *Default:* 30.0 *Unit:* meters	Specifies the transmit antenna height.
LINK-RX-ANTENNA-HEIGHT *Optional* *Scope:* All	Real *Range:* > 0.0 *Default:* 30.0 *Unit:* meters	Specifies the receive antenna height.
LINK-TX-ANTENNA-DISH-DIAMETER *Optional* *Scope:* All	Real *Range:* ≥ 0.01 *Default:* 0.8 *Unit:* meters	Specifies the transmit antenna dish diameter.
LINK-RX-ANTENNA-DISH-DIAMETER *Optional* *Scope:* All	Real *Range:* ≥ 0.01 *Default:* 0.8 *Unit:* meters	Specifies receive antenna dish diameter.

TABLE 4-82. Microwave Link Parameters

Parameter	Value	Description
LINK-TX-ANTENNA-CABLE-LOSS *Optional* *Scope:* All	Real *Range:* ≥ 0.0 *Default:* 1.5 *Unit:* dB	Specifies the transmit antenna cable loss. **Note:** In practice it should be less than 20 dB.
LINK-RX-ANTENNA-CABLE-LOSS *Optional* *Scope:* All	Real *Range:* ≥ 0.0 *Default:* 1.5 *Unit:* dB	Specifies receive antenna cable loss. **Note:** In practice it should be less than 20 dB.
LINK-TX-ANTENNA-POLARIZATION *Optional* *Scope:* All	List: • HORIZONTAL • VERTICAL *Default:* VERTICAL	Specifies the transmit antenna polarization.
LINK-RX-ANTENNA-POLARIZATION *Optional* *Scope:* All	List: • HORIZONTAL • VERTICAL *Default:* VERTICAL	Specifies the receive antenna polarization.
LINK-TX-POWER *Optional* *Scope:* All	Real *Range:* > 0.0 *Default:* 30.0 *Unit:* dBm	Specifies the transmit power.
LINK-RX-SENSITIVITY *Optional* *Scope:* All	Real *Range:* < 0.0 *Default:* -80.0 *Unit:* dBm	Specifies the receive sensitivity. It should be larger than the noise power.
LINK-NOISE-TEMPERATURE *Optional* *Scope:* All	Real *Default:* 290.0 *Unit:* °K	Specifies noise temperature. The higher the noise power, the larger the noise temperature.
LINK-NOISE-FACTOR *Optional* *Scope:* All	Real *Range:* ≥ 1.0 *Default:* 4.0	Specifies noise factor. The higher the noise power, the larger noise factor.

TABLE 4-82. Microwave Link Parameters

Parameter	Value	Description
`LINK-TERRAIN-TYPE` *Optional* *Scope:* All	List: • `PLAINS` • `HILLS` • `MOUNTAINS` *Default:* `PLAINS`	Specifies terrain type.
`LINK-PROPAGATION-RAIN-INTENSITY` *Optional* *Scope:* All	Real *Range:* `[0.0, 100.0]` *Default:* `0.0`	Specifies propagation rain intensity. **Note:** Refer to ITU-R Recommendation P.837-1 to find the rain intensity value for a desired area.
`LINK-PROPAGATION-TEMPERATURE` *Optional* *Scope:* All	Real *Range:* `[-20.0, 50.0]` *Default:* `25.0` *Unit:* °C	Specifies propagation temperature.
`LINK-PROPAGATION-SAMPLING-DISTANCE` *Optional* *Scope:* All	Real *Range:* `> 0.0` *Default:* `100.0` *Unit:* meters	Specifies propagation sampling distance.
`LINK-PROPAGATION-CLIMATE` *Optional* *Scope:* All	Integer *Range:* `[1, 7]` *Default:* `1`	Climate specification. The integer values correspond to the following: 1 : Equatorial 2 : Continental Subtropical 3 : Maritime Tropical 4 : Desert 5 : Continental Temperate 6 : Maritime Temperate, Over Land 7 : Maritime Temperate, Over Sea
`LINK-PROPAGATION-REFRACTIVITY` *Optional* *Scope:* All	Real *Range:* `≥ 280.0` *Default:* `360.0`	Specifies propagation refractivity. Its range starts from 280.0, where: 360.0 : Equatorial 320.0 : Continental Subtropical 370.0 : Maritime Tropical 280.0 : Desert 301.0 : Continental Temperate 320.0 : Maritime Temperate, Over Land 350.0 : Maritime Temperate, Over Sea

TABLE 4-82. Microwave Link Parameters

Parameter	Value	Description
`LINK-PROPAGATION-PERMITTIVITY` *Optional* *Scope:* All	Real *Range:* `[0.0, 99.0]` *Default:* `15.0`	Specifies propagation permittivity. 4.0 : Poor Ground 15.0 : Average Ground 25.0 : Good Ground 81.0 : Fresh Water 81.0 : Salt Water
`LINK-PROPAGATION-CONDUCTIVITY` *Optional* *Scope:* All	Real *Range:* `> 0.0` *Default:* `0.005`	Specifies propagation conductivity. Its value is generally a small number. Typical values are: 0.005 : Average Ground 0.001 : Poor Ground 0.02 : Good Ground 0.01 : Fresh Water 5.0 : Salt Water
`LINK-PROPAGATION-HUMIDITY` *Optional* *Scope:* All	Real *Range:* `[0.0, 100.0]` *Default:* `50.0`	Specifies propagation humidity. The value is defined as a percentage, where: 50.0 : Temperate Summer 80.0 : Temperate Winter
`LINK-PERCENTAGE-TIME-REFRACTIVITY-GRADIENT-LESS-STANDARD` *Optional* *Scope:* All	Real *Range:* `[0.0, 100.0]` *Default:* `15.0`	Specifies percentage time refractivity gradient less standard. **Note:** Refer to ITU-R Recommendation P.453-6 to find value for the desired area.
`MAC-LAYER-STATISTICS` *Optional* *Scope:* All	List: • `YES` • `NO` *Default:* `NO`	Specifies whether statistics are collected for MAC layer protocols.

4.9.3 GUI Configuration

This section describes how to configure Microwave Links in the GUI.

4.9.3.1 Configuring Symmetric Microwave Links

To configure parameters for a symmetric Microwave link, perform the following steps:

1. Go to the **Point-to-point Link Properties Editor > Point-to-point Link Properties > General**.
2. Set **Link Type** to *Microwave* and set the dependent parameters shown in Figure 4-57.

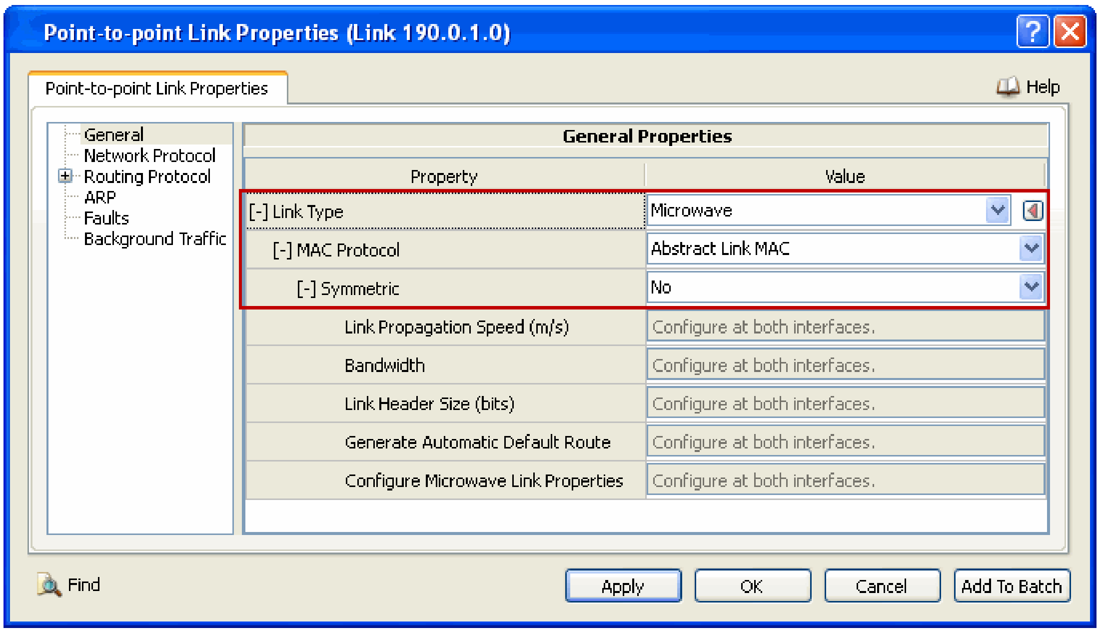


FIGURE 4-57. Setting Microwave Link Parameters

Setting Parameters

- To configure symmetric Microwave link, set **Symmetric** to *Yes*; otherwise set **Symmetric** to *No*.

3. If **Symmetric** is set to *Yes*, then set the dependent parameters listed in Table 4-83.

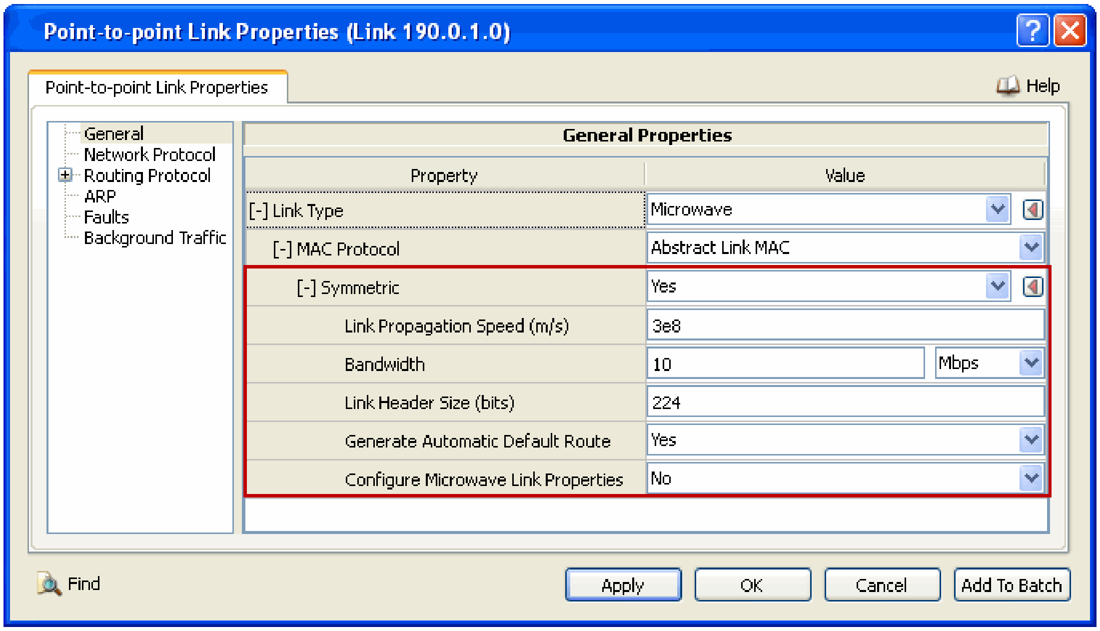


FIGURE 4-58. Setting Microwave Link MAC Properties

TABLE 4-83. Command Line Equivalent of Microwave Link MAC Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Link Propagation Speed	Subnet, Interface	`LINK-PROPAGATION-SPEED`
Bandwidth	Subnet, Interface	`LINK-BANDWIDTH`
Link Header Size	Subnet, Interface	`LINK-HEADER-SIZE-IN-BITS`
Generate Automatic Default Route	Subnet, Interface	`LINK-GENERATE-AUTOMATIC-DEFAULT-ROUTE`
Configure Microwave Link Properties	Subnet, Interface	N/A

Setting Parameters

- To configure Microwave Link properties, set **Configure Microwave Link Properties** to *Yes*; otherwise, set **Configure Microwave Link Properties** to *No*.

4. If **Symmetric** is set to *Yes* and **Configure Microwave Link Properties** is set to *Yes*, then set the dependent parameters listed in Table 4-84.

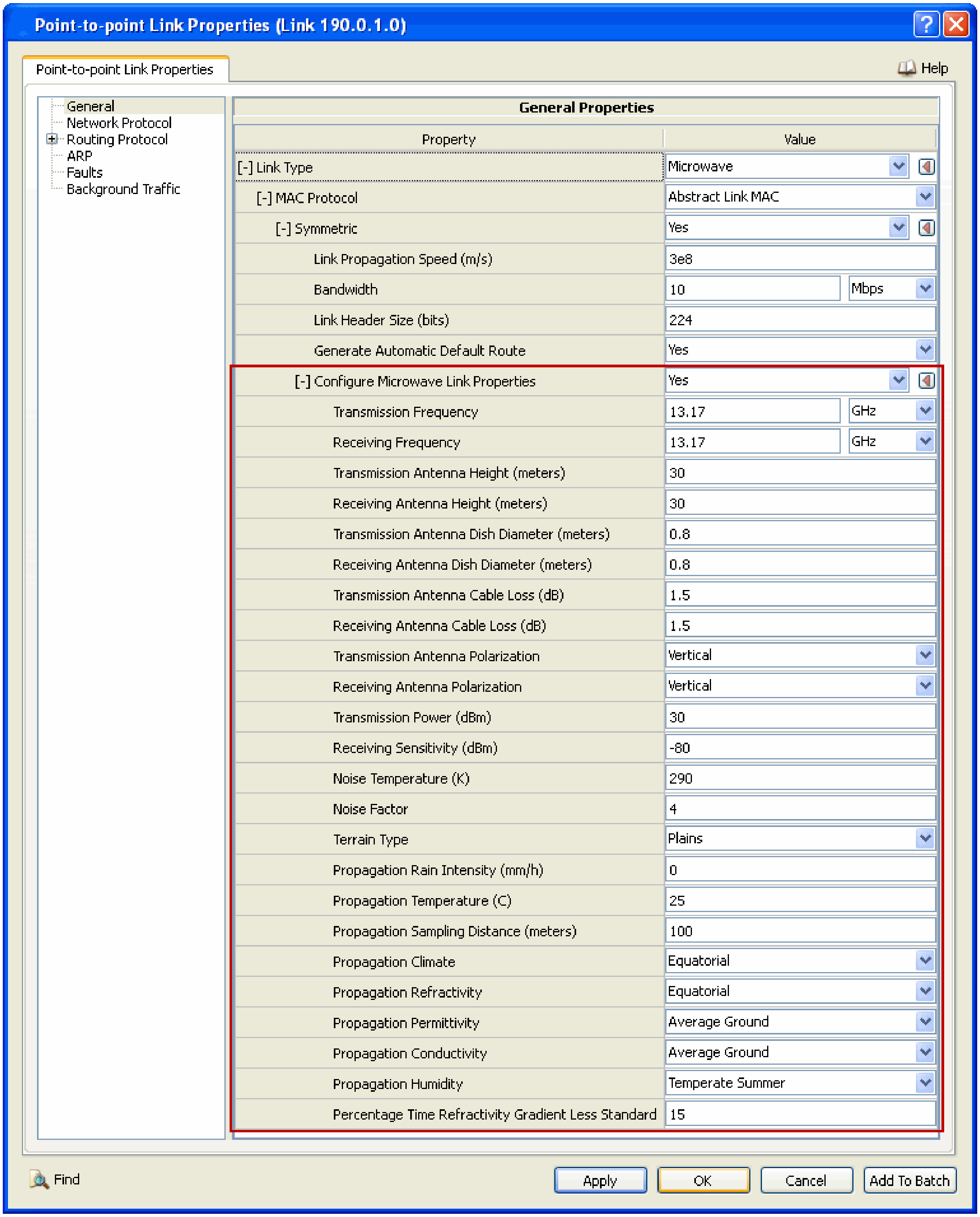


FIGURE 4-59. Configuring Microwave Link Properties

TABLE 4-84. Command Line Equivalent of Microwave Link Properties

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Transmission Frequency	Subnet, Interface	`LINK-TX-FREQUENCY`
Receiving Frequency	Subnet, Interface	`LINK-RX-FREQUENCY`
Transmission Antenna Height	Subnet, Interface	`LINK-TX-ANTENNA-HEIGHT`
Receiving Antenna Height	Subnet, Interface	`LINK-RX-ANTENNA-HEIGHT`
Transmission Antenna Dish Diameter	Subnet, Interface	`LINK-TX-ANTENNA-DISH-DIAMETER`
Receiving Antenna Dish Diameter	Subnet, Interface	`LINK-RX-ANTENNA-DISH-DIAMETER`
Transmission Antenna Cable Loss	Subnet, Interface	`LINK-TX-ANTENNA-CABLE-LOSS`
Receiving Antenna Cable Loss	Subnet, Interface	`LINK-RX-ANTENNA-CABLE-LOSS`
Transmission Antenna Polarization	Subnet, Interface	`LINK-TX-ANTENNA-POLARIZATION`
Receiving Antenna Polarization	Subnet, Interface	`LINK-RX-ANTENNA-POLARIZATION`
Transmission Power	Subnet, Interface	`LINK-TX-POWER`
Receiving Sensitivity	Subnet, Interface	`LINK-RX-SENSITIVITY`
Noise Temperature	Subnet, Interface	`LINK-NOISE-TEMPERATURE`
Noise Factor	Subnet, Interface	`LINK-NOISE-FACTOR`
Terrain Type	Subnet, Interface	`LINK-TERRAIN-TYPE`
Propagation Rain Intensity	Subnet, Interface	`LINK-PROPAGATION-RAIN-INTENSITY`
Propagation Temperature	Subnet, Interface	`LINK-PROPAGATION-TEMPERATURE`
Propagation Sampling Distance	Subnet, Interface	`LINK-PROPAGATION-SAMPLING-DISTANCE`
Propagation Climate	Subnet, Interface	`LINK-PROPAGATION-CLIMATE`
Propagation Refractivity	Subnet, Interface	`LINK-PROPAGATION-REFRACTIVITY`
Propagation Permittivity	Subnet, Interface	`LINK-PROPAGATION-PERMITTIVITY`
Propagation Conductivity	Subnet, Interface	`LINK-PROPAGATION-CONDUCTIVITY`
Propagation Humidity	Subnet, Interface	`LINK-PROPAGATION-HUMIDITY`
Percentage Time Refractivity Gradient Less Standard	Subnet, Interface	`LINK-PERCENTAGE-TIME-REFRACTIVITY-GRADIENT-LESS-STANDARD`

4.9.3.2 Configuring Asymmetric Microwave Links

To configure parameters for an asymmetric Microwave link, perform the following steps:

1. Configure the link to be an asymmetric link, as described in Section 4.9.3.1.
2. For each interface of the link, configure the parameters as follows:
   a. Go to **Interface Properties Editor > Interfaces > Interface # > MAC Layer**.
   b. Set the dependent parameters listed in Table 4-85.

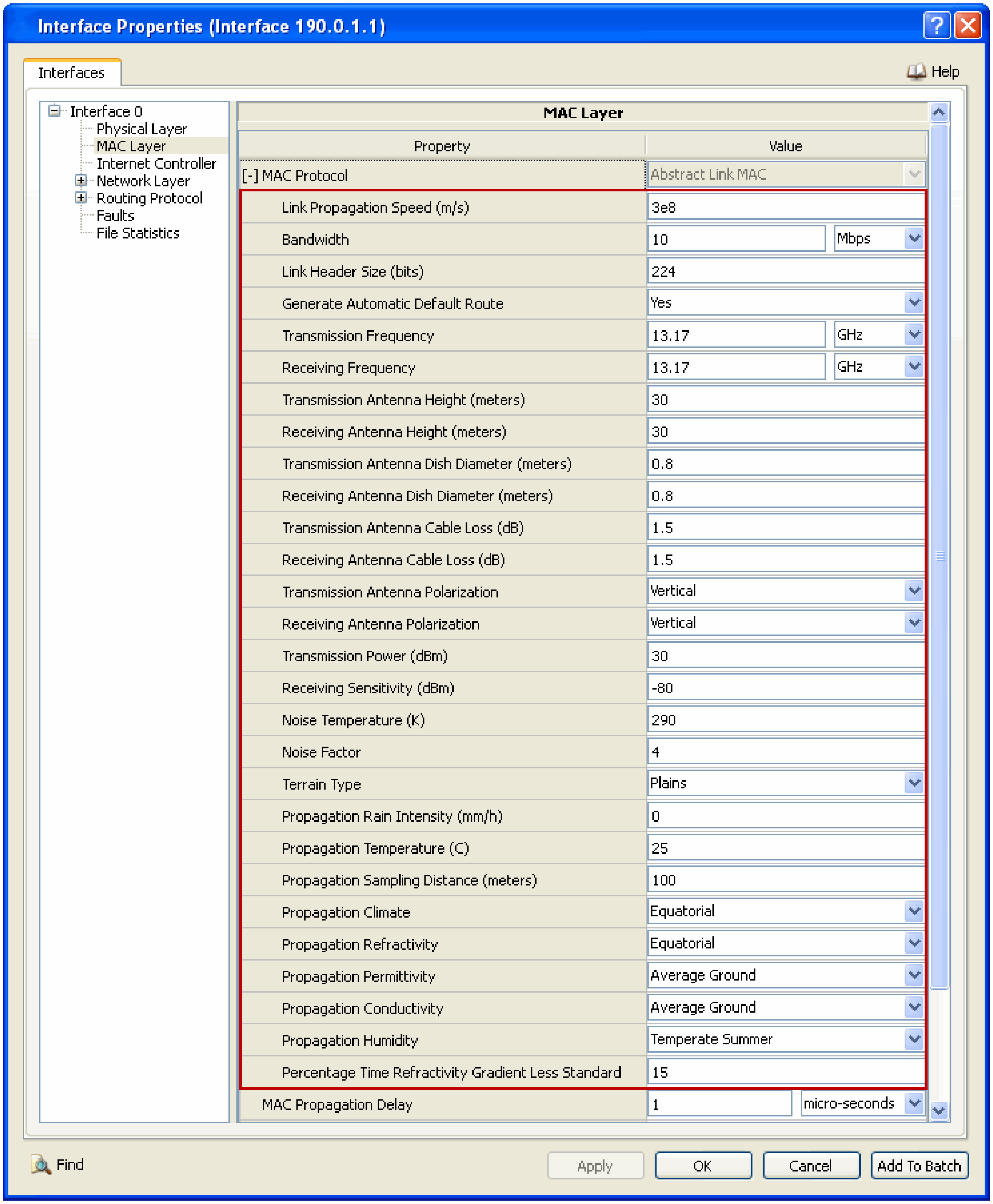


FIGURE 4-60. Setting Asymmetric Microwave Link Parameters

TABLE 4-85. Command Line Equivalent of Asymmetric Microwave Link Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Link Propagation Delay	Interface	`LINK-PROPAGATION-DELAY`
Bandwidth	Interface	`LINK-BANDWIDTH`
Link Header Size	Interface	`LINK-HEADER-SIZE-IN-BITS`
Transmission Frequency	Interface	`LINK-TX-FREQUENCY`
Receiving Frequency	Interface	`LINK-RX-FREQUENCY`
Transmission Antenna Height	Interface	`LINK-TX-ANTENNA-HEIGHT`
Receiving Antenna Height	Interface	`LINK-RX-ANTENNA-HEIGHT`
Transmission Antenna Dish Diameter	Interface	`LINK-TX-ANTENNA-DISH-DIAMETER`
Receiving Antenna Dish Diameter	Interface	`LINK-RX-ANTENNA-DISH-DIAMETER`
Transmission Antenna Cable Loss	Interface	`LINK-TX-ANTENNA-CABLE-LOSS`
Receiving Antenna Cable Loss	Interface	`LINK-RX-ANTENNA-CABLE-LOSS`
Transmission Antenna Polarization	Interface	`LINK-TX-ANTENNA-POLARIZATION`
Receiving Antenna Polarization	Interface	`LINK-RX-ANTENNA-POLARIZATION`
Transmission Power	Interface	`LINK-TX-POWER`
Receiving Sensitivity	Interface	`LINK-RX-SENSITIVITY`
Noise Temperature	Interface	`LINK-NOISE-TEMPERATURE`
Noise Factor	Interface	`LINK-NOISE-FACTOR`
Terrain Type	Interface	`LINK-TERRAIN-TYPE`
Propagation Rain Intensity	Interface	`LINK-PROPAGATION-RAIN-INTENSITY`
Propagation Temperature	Interface	`LINK-PROPAGATION-TEMPERATURE`
Propagation Sampling Distance	Interface	`LINK-PROPAGATION-SAMPLING-DISTANCE`
Propagation Climate	Interface	`LINK-PROPAGATION-CLIMATE`
Propagation Refractivity	Interface	`LINK-PROPAGATION-REFRACTIVITY`
Propagation Permittivity	Interface	`LINK-PROPAGATION-PERMITTIVITY`
Propagation Conductivity	Interface	`LINK-PROPAGATION-CONDUCTIVITY`
Propagation Humidity	Interface	`LINK-PROPAGATION-HUMIDITY`
Percentage Time Refractivity Gradient Less Standard	Interface	`LINK-PERCENTAGE-TIME-REFRACTIVITY-GRADIENT-LESS-STANDARD`

4.9.3.3 Configuring Statistics Parameters

Statistics for the Microwave Link model can be collected at the global, node, subnet, and interface levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for Microwave Link, check the box labeled **MAC** in the appropriate properties editor.

TABLE 4-86. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
MAC	Global, Node, Subnet, Interface	`MAC-LAYER-STATISTICS`

4.9.4 Statistics

This section describes the file, database, and dynamic statistics of the Microwave Link model.

4.9.4.1 File Statistics

Table 4-87 shows the Microwave Link statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 4-87. Microwave Link Statistics

Statistic	Description
Destination	Shows the destination node ID for the link
Link Utilization	Shows the link usage (see note.)
Unicast data frames sent to the phy layer (frames)	Total number of unicast data frames sent to the link.
Unicast data frames received from phy layer (frames)	Total number of unicast data frames received on the link.
Unicast control frames sent to the phy layer (frames)	Total number of unicast control frames sent to the link.
Unicast control frames received from phy layer (frames)	Total number of unicast control frames received on the link.
Unicast data bytes sent to the phy layer (bytes)	Total number of unicast data bytes sent to the link.
Unicast data bytes received from phy layer (bytes)	Total number of unicast data bytes received on the link.
Unicast control bytes sent to the phy layer (bytes)	Total number of unicast control bytes sent to the link.
Unicast control bytes received from phy layer (bytes)	Total number of unicast control bytes received on the link.
Average delay for Unicast packets in output queue at the mac layer (seconds)	Average delay in output queue at the MAC layer for unicast packets.
Average delay to gain access to medium at the mac layer for Unicast packets (seconds)	Average delay to gain access to medium at the MAC layer for unicast packets.
Average medium delay (transmission + propagation) at the mac layer for Unicast packets (seconds)	Average medium delay (transmission + propagation) at the MAC layer for unicast packets.
Average jitter at the mac layer for Unicast packets (seconds)	Average jitter at the MAC layer for the unicast packets.
Broadcast data frames sent to the phy layer (frames)	Total number of broadcast data frames sent to the link.
Broadcast data frames received from phy layer (frames)	Total number of broadcast data frames received on the link.
Broadcast control frames sent to the phy layer (frames)	Total number of broadcast control frames sent to the link.
Broadcast control frames received from phy layer (frames)	Total number of broadcast control frames received on the link.
Broadcast data bytes sent to the phy layer (bytes)	Total number of broadcast data bytes sent to the link.

TABLE 4-87. Microwave Link Statistics (Continued) (Continued)

Statistic	Description
Broadcast data bytes received from phy layer (bytes)	Total number of broadcast data bytes received on the link.
Broadcast control bytes sent to the phy layer (bytes)	Total number of control bytes sent to the link.
Broadcast control bytes received from phy layer (bytes)	Total number of control bytes received on the link.
Average delay for Broadcast packets in output queue at the mac layer (seconds)	Average delay in output queue at the MAC layer for broadcast packets.
Average delay to gain access to medium at the mac layer for Broadcast packets (seconds)	Average delay to gain access to medium at the MAC layer for broadcast packets.
Average medium delay (transmission + propagation) at the mac layer for Broadcast packets (seconds)	Average medium delay (transmission + propagation) at the MAC layer for broadcast packets.
Average jitter at the mac layer for Broadcast packets (seconds)	Average jitter at the MAC layer for broadcast packets.
Multicast data frames sent to the phy layer (frames)	Total number of multicast data frames sent to the link.
Multicast data frames received from phy layer (frames)	Total number of multicast data frames received on the link.
Multicast control frames sent to the phy layer (frames)	Total number of multicast control frames sent to the link.
Multicast control frames received from phy layer (frames)	Total number of multicast control frames received from the link.
Multicast data bytes sent to the phy layer (bytes)	Total number of multicast data bytes sent to the link.
Multicast data bytes received from phy layer (bytes)	Total number of multicast data bytes received on the link.
Multicast control bytes sent to the phy layer (bytes)	Total number of multicast control bytes sent to the link.
Multicast control bytes received from phy layer (bytes)	Total number of multicast control bytes received on the link.
Average delay for Multicast packets in output queue at the mac layer (seconds)	Average delay in output queue at the MAC layer for multicast packets.
Average delay to gain access to medium at the mac layer for Multicast packets (seconds)	Average delay to gain access to medium at the MAC layer for multicast packets.
Average medium delay (transmission + propagation) at the mac layer for Multicast packets (seconds)	Average medium delay (transmission + propagation) at the MAC layer for multicast packets.
Average jitter at the mac layer for Multicast packets (seconds)	Average jitter at the MAC layer for multicast packets.
Carried load at the mac layer (bits/second)	Carried load at the MAC layer.

Note: The link utilization is given by the ratio (total time the channel is busy)/(simulation time).

4.9.4.2 Database Statistics

In addition to the file statistics, the Microwave Link model also enters statistics in various scenario statistics database tables. Refer to *EXata Statistics Database User's Guide* for details.

4.9.4.3 Dynamic Statistics

No dynamic statistics are supported for the Microwave Link model.

4.9.5 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the Microwave Link model. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/microwave. Table 4-88 lists the sub-directory where each scenario is located.

TABLE 4-88. Microwave Link Scenarios Included in EXata

Scenario	Description
microwave	To test microwave link functionality.

4.10 Multiple Access Collision Avoidance (MACA) MAC Protocol

4.10.1 Description

Multiple Access Collision Avoidance (MACA) is a wireless MAC protocol that uses an RTS/CTS dialog to solve the hidden terminal problem. It does not use carrier sensing. MACA can also easily be extended so that it provides automatic transmitter power control. Doing this can substantially increase the channel capacity.

4.10.2 Command Line Configuration

To specify MACA as the MAC protocol, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]  MAC-PROTOCOL         MACA
```

The scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

MACA Parameters

Table 4-89 shows the configuration parameter for the MACA model:

TABLE 4-89. MACA Configuration Parameter

Parameter	Value	Description
`MAC-LAYER-STATISTICS` *Optional* Scope: All	List • `YES` • `NO` *Default:* `NO`	Indicates whether statistics are collected for MAC layer protocols, including MACA.

4.10.3 GUI Configuration

This section describes how to configure Multiple Access Collision Avoidance (MACA) MAC Protocol in the GUI.

Configuring MACA MAC Protocol Parameters

To configure the MACA MAC Protocol parameters, perform the following steps:

1. Go to one of the following locations:
    - To set wireless subnet properties, go to **Wireless Subnet Properties Editor > MAC Layer > MAC Protocol**.
    - To set properties for a specific interface of a node, go to **Node Interfaces Properties Editor > Interface # > MAC Layer > MAC Protocol**.

    In this section, we show how to configure MACA MAC Protocol parameters for a specific interface using the Default Device Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **MAC Protocol** to *MACA*. There are no dependent parameters for this model.

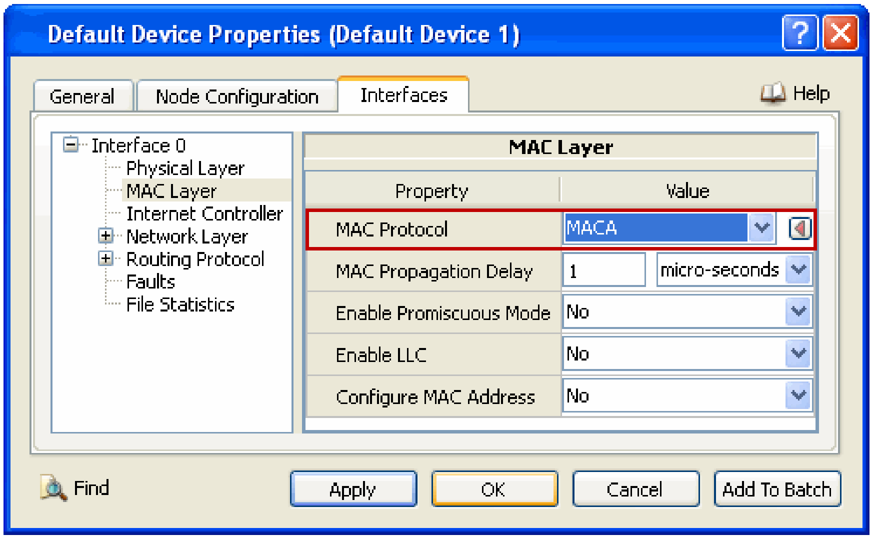


FIGURE 4-61. Setting MAC Protocol to MACA

Configuring Statistics Parameters

Statistics for the MACA model can be collected at the global, node, subnet, and interface levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for MACA, check the box labeled **MAC** in the appropriate properties editor.

TABLE 4-90. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
MAC	Global, Node, Subnet, Interface	`MAC-LAYER-STATISTICS`

4.10.4 Statistics

Table 4-91 shows the MACA statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 4-91. MACA Statistics

Statistic	Description
Packets from network	Number of data packets received from upper layer.
Packets lost due to buffer overflow	Number of data packets dropped due to buffer overflow.
UNICAST packets sent to channel	Number of unicast packets sent to the channel.
BROADCAST packets sent to channel	Number of broadcast packets sent to the channel.
UNICAST packets received	Number of unicast packets received successfully.
BROADCAST packets received	Number of broadcast packets received successfully.
RTS Packets sent	Number of RTS control packets sent.
CTS Packets sent	Number of CTS control packets sent.

TABLE 4-91. MACA Statistics (Continued)

Statistic	Description
RTS Packets received	Number of RTS control packets received.
CTS Packets received	Number of CTS control packets received.
Noisy Packets received	Number of packets received whose destination address is not the node.

4.11 Time Division Multiple Access (TDMA) MAC Protocol

4.11.1 Description

Time Division Multiple Access (TDMA) is a multiplexing protocol that splits the channel into distinct time slots for different transmitters. By default, these slots are assigned to nodes on a round-robin basis. Users can also specify a slot assignment file to manually assign slots to transmitters.

4.11.2 Command Line Configuration

To specify TDMA as the MAC protocol, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   MAC-PROTOCOL      TDMA
```

This scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

TDMA Parameters

Table 4-92 describes the TDMA configuration parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 4-92. TDMA Parameters

Parameter	Value	Description
`TDMA-NUM-SLOTS-PER-FRAME` *Optional* *Scope:* All	Integer *Range:* `> 0` *Default:* number of nodes in scenario	Specifies the number of slots to be assigned to transmitters.
`TDMA-SLOT-DURATION` *Optional* *Scope:* All	Time *Range:* `> 0S` *Default:* `10MS`	Specifies the length of the slot in EXata Time Format.
`TDMA-GUARD-TIME` *Optional* *Scope:* All	Time *Range:* ≥ `0S` *Default:* `0S`	Specifies the amount of time in between slots. No transmitters transmit during this interval; it provides a buffer between slots to handle clock jitter.
`TDMA-INTER-FRAME-TIME` *Optional* *Scope:* All	Time *Range:* ≥ `0S` *Default:* `1US`	Specifies a buffer between entire frames.

TABLE 4-92. TDMA Parameters (Continued)

Parameter	Value	Description
`TDMA-SCHEDULING` *Optional* *Scope:* All	List: • `AUTOMATIC` • `FILE` *Default:* `AUTOMATIC`	Specifies the slot assignment. `AUTOMATIC` : Slots are assigned to nodes on a round-robin basis `FILE` : Slots can be assigned manually to every TDMA transmitter.
`TDMA-SCHEDULING-FILE` *Optional* *Scope:* All	Filename	Specifies the name of the TDMA scheduling file. The format of the TDMA scheduling file is described in Section 4.11.2.1.
`MAC-LAYER-STATISTICS` *Optional* *Scope:* All	List: • `YES` • `NO` *Default:* `NO`	Indicates whether routing protocol statistics are collected for TDMA MAC protocol.

4.11.2.1 Format of the TDMA Scheduling File

Each line of the TDMA scheduling file specifies the state of each node (transmitting, receiving, or idle) in one slot.

Each line in the TDMA scheduling file has the following format:

```
<slot-ID> <node-ID-1>-<mode-1> ... <node-ID-n>-<mode-n>
```

where

`<slot-ID>` Slot identification number.

`<node-ID-i>` Node ID for *i*th node or the string “`All`”.

`<mode-i>` Mode of the *i*th node. This can be “`Rx`” (if the node is in receiving mode in the slot) or “`Tx`” (if the node is in transmitting mode in t he slot). If `<node-ID-i>` is “`All`”, then `<mode-i>` applies to all nodes.

Notes:
1. If no mode (Rx or Tx) is specified for a node in a slot, then that node is in idle mode in that slot
2. More than one mode can be specified for a node in a slot. In that case, the transmit mode (Tx) takes precedence.

Example

The following lines are examples of entries in the TDMA scheduling file. The first line specifies that in slot 0, nodes 1 and 3 are in receiving mode, node 2 is in transmitting mode, and the rest of the nodes are in idle mode. The last line specifies that in slot 3, node 3 is in transmitting mode and all the other nodes are in receiving mode.

```
0 1-Rx 2-Tx 3-Rx
1 1-Tx 2-Rx 3-Rx
2 1-Rx 2-Rx 3-Tx
3 All-Rx 3-Tx
```

4.11.3 GUI Configuration

This section describes how to configure Time Division Multiple Access (TDMA) MAC Protocol in the GUI.

Configuring TDMA MAC Protocol Parameters

To configure the TDMA MAC Protocol parameters, perform the following steps:

1. Go to one of the following locations:
   - To set wireless subnet properties, go to **Wireless Subnet Properties Editor > MAC Layer > MAC Protocol**.
   - To set properties for a specific interface of a node, go to **Node Interfaces Properties Editor > Interface # > MAC Layer > MAC Protocol**.

   In this section, we show how to configure TDMA parameters for a specific interface using the Default Device Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **MAC Protocol** to *TDMA* and dependent parameters of the model, as listed in Table 4-93.

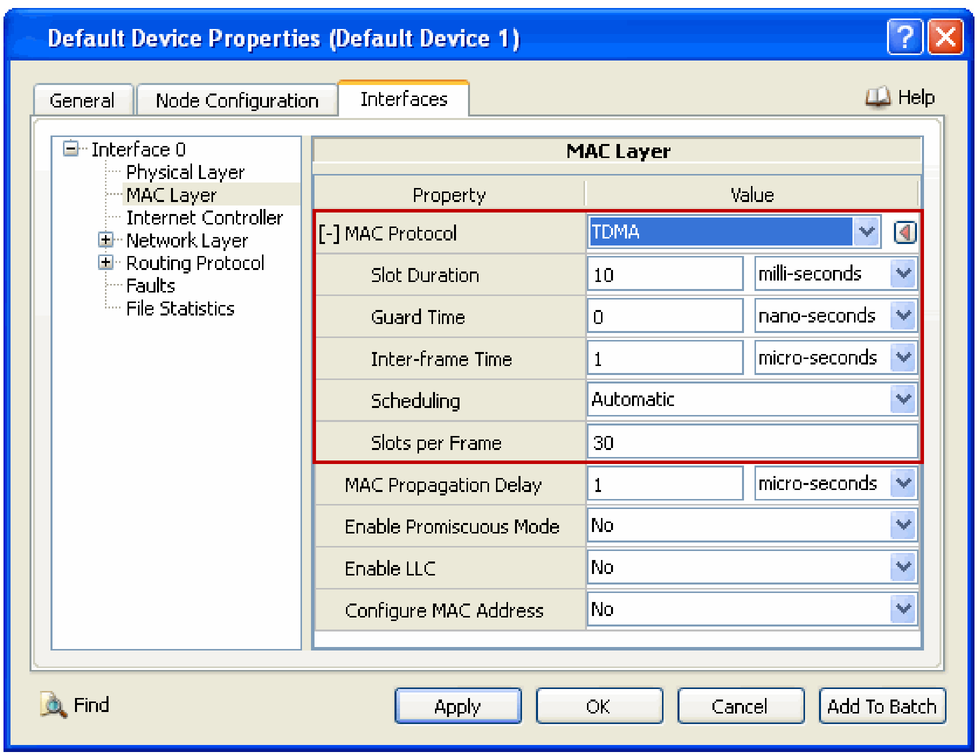


FIGURE 4-62. Setting TDMA parameters

TABLE 4-93. Command Line Equivalent of IP Queue Weight Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Slot Duration	Subnet, Interface	`TDMA-SLOT-DURATION`
Guard Time	Subnet, Interface	`TDMA-GUARD-TIME`
Inter-frame Time	Subnet, Interface	`TDMA-INTER-FRAME-TIME`
Scheduling	Subnet, Interface	`TDMA-SCHEDULING`
Slots per Frame	Subnet, Interface	`TDMA-NUM-SLOTS-PER-FRAME`

3. If **Scheduling** is set to *File*, User can specify his own Scheduling file. Set the dependent parameter as listed in Table 4-94.

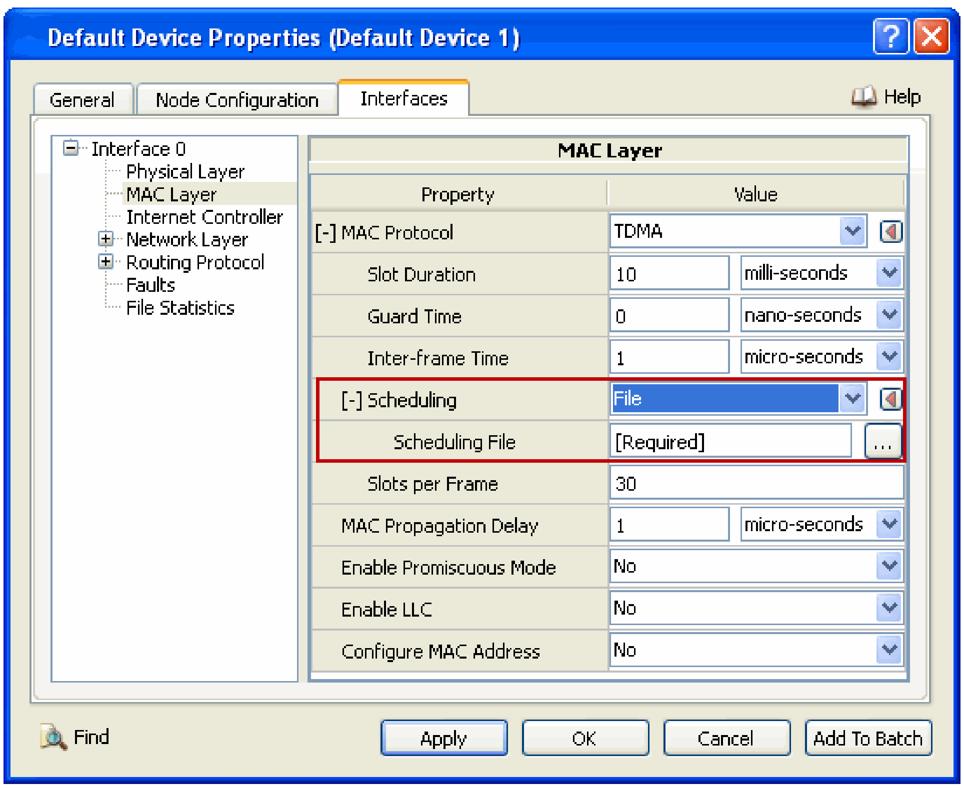


FIGURE 4-63. Setting Scheduling Parameters

TABLE 4-94. Command Line Equivalent of Scheduling Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Scheduling File	Interface, Subnet	`TDMA-SCHEDULING-FILE`

Configuring Statistics Parameters

Statistics for the TDMA MAC model can be collected at the global, node, subnet, and interface levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for TDMA, check the box labeled **MAC** in the appropriate properties editor.

TABLE 4-95. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
MAC	Global, Node, Subnet, Interface	`MAC-LAYER-STATISTICS`

4.11.4 Statistics

Table 4-96 shows the TDMA statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 4-96. TDMA Statistics

Statistic	Description
UNICAST packets sent to the channel	Packets with a specific destination address transmitted on the channel
BROADCAST packets sent to the channel	Packets broadcasted to all radios within transmission range
UNICAST packets received	Packets destined for this specific radio and successfully received
BROADCAST packets received	Packets destined for all radios and successfully received by this radio

4.11.5 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the TDMA model. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/tdma. Table 4-97 lists the sub-directory where each scenario is located.

TABLE 4-97. TDMA Scenarios Included in EXata

Scenario	Description
tdma-contention	Shows the behavior of TDMA when contention occur in TDMA slot.
tdma-default	Shows the behavior of TDMA when no contention occur in TDMA slot.

5 Unicast Routing Protocol Models

This chapter describes features, configuration requirements and parameters, statistics, and scenarios for Unicast Routing Protocol Models, and consists of the following sections:

- Ad-Hoc On Demand Distance Vector (AODV) Routing Protocol
- Bordercast Resolution Protocol (BRP)
- Dynamic MANET On-demand (DYMO) Routing Protocol
- Dynamic Source Routing (DSR) Protocol
- Fisheye State Routing Protocol
- Intrazone Routing Protocol (IARP)
- Interzone Routing Protocol (IERP)
- Landmark Ad Hoc Routing (LANMAR) Protocol
- Location-Aided Routing (LAR) Protocol
- Optimized Link State Routing Protocol - INRIA (OLSR-INRIA)
- Optimized Link State Routing Protocol version 2 (OLSRv2)
- Source Tree Adaptive Routing (STAR) Protocol
- Zone Routing Protocol (ZRP)

5.1 Ad-hoc On-demand Distance Vector (AODV) Routing Protocol

The EXata Ad-hoc On-demand Distance Vector (AODV) model is based on RFC 3561.

5.1.1 Description

AODV protocol is specially used for mobile ad hoc networks. It provides a quick adaptation to dynamic link condition, link fault, low processing and memory usage overhead. It enables dynamic, self-starting, multihop routing between participating mobile nodes wishing to establish and maintain an ad hoc network.

AODV allows mobile nodes to obtain routes quickly for new destinations, and does not require nodes to maintain routes to destinations that are not in active communication. AODV allows mobile nodes to respond to link breakages and changes in network topology in a timely manner. It uses sequence numbers to prevent routing loops.

5.1.2 Features and Assumptions

This section describes the implemented features, omitted features, assumptions and limitations of the AODV model.

5.1.2.1 Implemented Features

- Support for both IPv4 and IPv6 networks
- RREQ, RREP and RERR messages
- Expanding ring search technique to prevent dissemination of RREQ packets
- Hello message
- Route Reply Acknowledgement
- Local Repair
- Compatibility with MAC protocols other than 802.11

5.1.2.2 Omitted Features

- Shifting the protocol in application layer to use UDP/654
- Implementation of Subnet Leader
- Network layer link detection using passive acknowledgement
- Hello interval extension
- Multicast extension
- Dynamic timeout determination
- Implementation of infrastructure router

5.1.2.3 Assumptions and Limitations

- The D (destination only flag) and U (unknown sequence number) flags are included though they are not in the draft for IPv6
- When a node tries to find a better route, it deletes the previous valid route and initiates a route request. For example, if a node has a route which is expired or invalidated or in the case when it receives a Route Error (RERR), an RREQ is generated after deleting the current route
- For sending Gratuitous Route reply, draft 10 specification has been used instead of draft 9
- For updating lifetime during forwarding a packet, draft 10 specification has been taken instead of draft 9 which says to update the lifetime of the next hop towards the destination

- Route time-outs time for neighbors has been taken from draft 10 instead of draft 9 which is ALLOWED_HELLO_LOSS *HELLO_INTERVAL instead of ACTIVE_ROUTE_TIMEOUT.

5.1.3 Command Line Configuration

To select AODV as the routing protocol, include the following parameter(s) in the scenario configuration (.config) file:

- For an IPv4 node, use the following parameter:

```
[<Qualifier>] ROUTING-PROTOCOL          AODV
```

- For an IPv6 node, use *either* of the following parameters:

```
[<Qualifier>] ROUTING-PROTOCOL          AODV
```

or

```
[<Qualifier>] ROUTING-PROTOCOL-IPv6     AODV
```

- For a dual IP-node, use *both* the following parameters:

```
[<Qualifier>] ROUTING-PROTOCOL          AODV
```

and

```
[<Qualifier>] ROUTING-PROTOCOL-IPv6     AODV
```

The scope of these parameter declarations can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

AODV Parameters

AODV configuration parameters are described in Table 5-1. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 5-1. AODV Parameters

Parameter	Value	Description
AODV-DEST-ONLY-NODE Optional *Scope:* All	List: • YES • NO *Default:* NO	Specifies whether intermediate nodes having route to the destination will respond to an incoming RREQ. If set to YES, only destination node will respond to an RREQ.
AODV-NET-DIAMETER Optional *Scope:* All	Integer *Range:* > 0 *Default:* 35	Specifies the maximum possible number of hops between two nodes in the network.
AODV-NODE-TRAVERSAL-TIME Optional *Scope:* All	Time *Range:* > 0S *Default:* 40MS	Specifies the conservative estimate of the average one-hop traversal time for packets and should include queuing, transmission, propagation and other delays.

TABLE 5-1. AODV Parameters (Continued)

Parameter	Value	Description
AODV-ACTIVE-ROUTE-TIMEOUT Optional *Scope:* All	Time *Range:* > 0S *Default:* 3000MS	Specifies the expiry time for an active route; each time a route is used, the lifetime of that route is updated by this value.
AODV-MY-ROUTE-TIMEOUT Optional *Scope:* All	Time *Range:* > 0S *Default:* (2 * AODV-ACTIVE-ROUTE-TIMEOUT)	Specifies the destination of a RREQ replies with AODV-MY-ROUTE-TIMEOUT as the lifetime of the route.
AODV-PROCESS-HELLO Optional *Scope:* All	List: • YES • NO *Default:* NO	Specifies whether hello messages will be used to maintain connectivity with neighbors.
AODV-HELLO-INTERVAL Optional *Scope:* All	Time *Range:* > 0S *Default:* 100MS	Specifies the time interval for which a node waits to broadcast the next hello message. Applicable when AODV-PROCESS-HELLO is set to YES.
AODV-ALLOWED-HELLO-LOSS Optional *Scope:* All	Integer *Range:* > 0 *Default:* 2	Specifies the number of hello intervals to wait before flagging the neighboring link as broken. Applicable when AODV-PROCESS-HELLO is set to YES.
AODV-RREQ-RETRIES Optional *Scope:* All	Integer *Range:* > 0 *Default:* 2	Specifies the maximum number of times expanded ring search for a destination will be repeated if no route was found during previous attempts.
AODV-ROUTE-DELETION-CONSTANT Optional *Scope:* All	Integer *Range:* > 0 *Default:* 5	Specifies a constant, which is used for calculating the time after which an active route must be deleted. After timeout of an active route, the route is deleted from the routing table after a time period of K * max (AODV-ACTIVE-ROUTE-TIMEOUT, AODV-ALLOWED-HELLO-LOSS * AODV-HELLO-INTERVAL). Here, K is the value of AODV-ROUTE-DELETION-CONSTANT.
AODV-LOCAL-REPAIR Optional *Scope:* All	List: • YES • NO *Default:* NO	Specifies whether a node will attempt to locally repair a broken route to a destination.

TABLE 5-1. AODV Parameters (Continued)

Parameter	Value	Description
AODV-SEARCH-BETTER-ROUTE Optional *Scope:* All	List: • YES • NO *Default:* NO	Specifies whether a node will delete a route from its routing table on reception of a route error packet from the next hop towards the destination.
AODV-BUFFER-MAX-PACKET Optional *Scope:* All	Integer *Range:* > 0 *Default:* 100 *Unit:* packets	Specifies the maximum number of packets AODV buffer can hold at any given time irrespective of the packet size.
AODV-BUFFER-MAX-BYTE Optional *Scope:* All	Integer *Range:* ≥ 0 *Default:* 0 *Unit:* Bytes	Specifies the maximum size of AODV buffer in bytes. If no value or zero is specified to this parameter, AODV-BUFFER-MAX-PACKET will be used to determine the size of the buffer.
AODV-OPEN-BI-DIRECTIONAL-CONNECTION Optional *Scope:* All	List: • YES • NO *Default:* NO	Specifies whether a node will send a gratuitous Route Reply packet to the destination node on reception of an Route Request packet.
AODV-TTL-START Optional *Scope:* All	Integer *Range:* > 0 *Default:* 1	Specifies the number of hops a route request message will traverse to search for a destination while initiating a route request.
AODV-TTL-INCREMENT Optional *Scope:* All	Integer *Range:* > 0 *Default:* 2	Specifies the value by which the TTL is incremented, each time when a Route Request is retransmitted.
AODV-TTL-THRESHOLD Optional *Scope:* All	Integer *Range:* > 0 *Default:* 7	Specifies the TTL value up to which AODV-TTL-INCREMENT will be used to increment the TTL. After this value, AODV-NET-DIAMETER will used as the TTL.
AODV-PROCESS-ACK Optional *Scope:* All	List: • YES • NO *Default:* NO	Specifies weather a node needs an acknowledgement in return after transmitting a Route Reply packet.

TABLE 5-1. AODV Parameters (Continued)

Parameter	Value	Description
`ROUTING-STATISTICS` Optional *Scope:* Global, Node	List: • `YES` • `NO` *Default:* `YES`	Indicates whether statistics are collected for routing protocols, including AODV.
`TRACE-AODV` Optional *Scope:* Global, Node *Instances:* No	List: • `YES` • `NO` *Default:* `NO`	Indicates whether packet tracing is enabled for AODV. **Note:** To enable packet tracing, some other parameters need to be configured as well. Refer to Section 4.2.10 of *EXata User's Guide* for details.

5.1.4 GUI Configuration

This section describes how to configure AODV for an IPv4 node in the GUI. AODV can be configured in a similar way for an IPv6 or Dual IP node.

Configuring AODV Parameters

To configure the AODV parameters, perform the following steps:

1. Go to one of the following locations:
   - To set properties for a specific wireless subnet, go to **Wireless Subnet Properties Editor > Routing Protocol > General**.
   - To set properties for a specific wired subnet, go to **Wired Subnet Properties Editor > Routing Protocol > General**.
   - To set properties for a specific point-to-point link, go to **Point-to-point Link Properties Editor > Point-to-point Link Properties > Routing Protocol**.
   - To set properties for a specific node, go to **Default Device Properties Editor > Node Configuration > Routing Protocol**.
   - To set properties for a specific interface of a node, go to one of the following locations:
     - **Interface Properties Editor > Interfaces > Interface # > Routing Protocol**.
     - **Default Device Properties Editor > Interfaces > Interface # > Routing Protocol**.

In this section, we show how to configure AODV parameters for a specific node using the Default Device Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **Routing Protocol IPv4** to *AODV* and set the dependent parameters listed in Table 5-2.

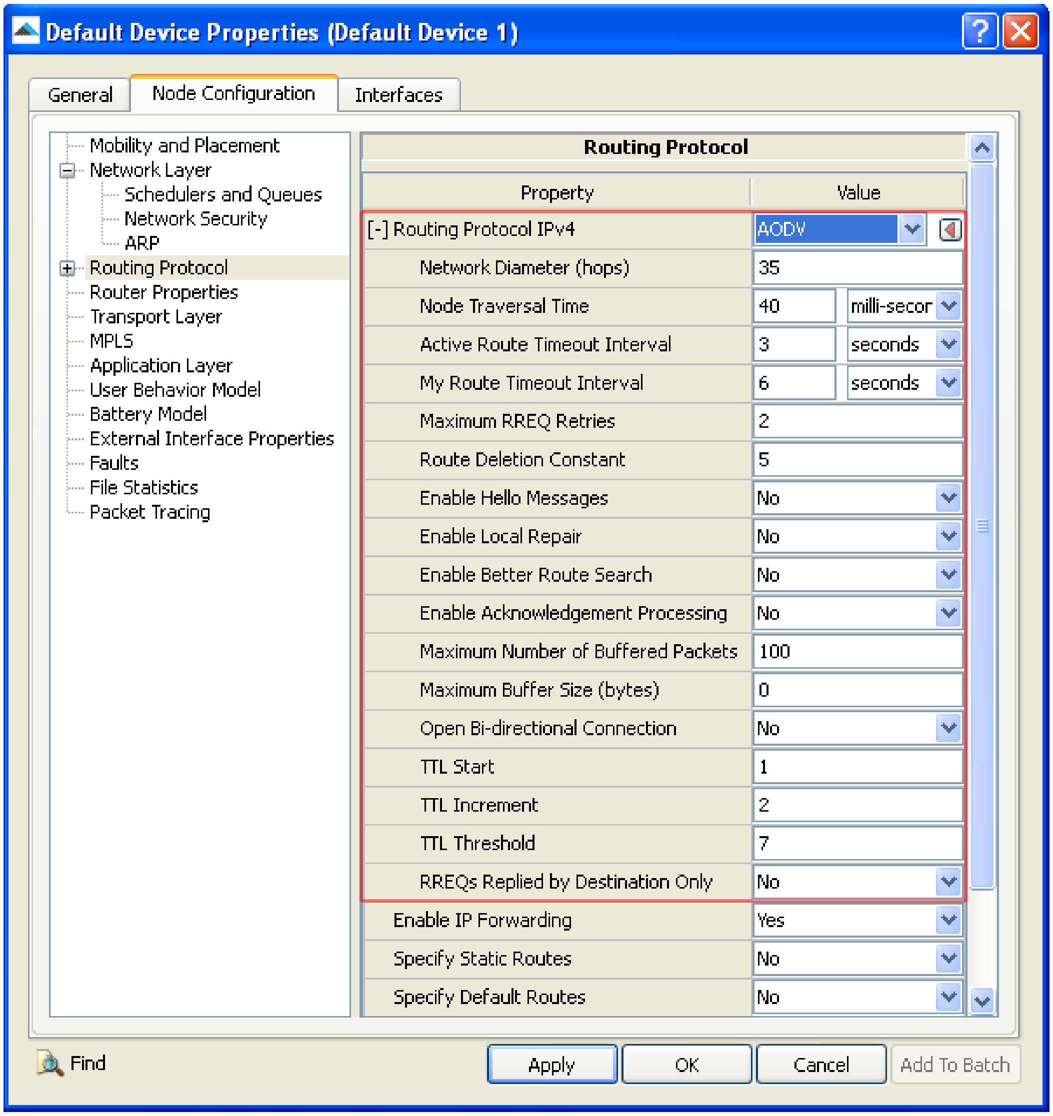


FIGURE 5-1. Setting AODV Parameters

TABLE 5-2. Command Line Equivalent of AODV Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Network Diameter	Node, Subnet, Interface	`AODV-NET-DIAMETER`
Node Traversal Time	Node, Subnet, Interface	`AODV-NODE-TRAVERSAL-TIME`
Active Route Timeout Interval	Node, Subnet, Interface	`AODV-ACTIVE-ROUTE-TIMEOUT`
My Route Timeout Interval	Node, Subnet, Interface	`AODV-MY-ROUTE-TIMEOUT`
Maximum RREQ Retries	Node, Subnet, Interface	`AODV-RREQ-RETRIES`
Route Deletion Constant	Node, Subnet, Interface	`AODV-ROUTE-DELETION-CONSTANT`
Enable Hello Messages	Node, Subnet, Interface	`AODV-PROCESS-HELLO`
Enable Local Repair	Node, Subnet, Interface	`AODV-LOCAL-REPAIR`
Enable Better Route Search	Node, Subnet, Interface	`AODV-SEARCH-BETTER-ROUTE`
Enable Acknowledgement Processing	Node, Subnet, Interface	`AODV-PROCESS-ACK`
Maximum Number of Buffered Packets	Node, Subnet, Interface	`AODV-BUFFER-MAX-PACKET`
Maximum Buffer Size	Node, Subnet, Interface	`AODV-BUFFER-MAX-BYTE`
Open Bi-directional Connection	Node, Subnet, Interface	`AODV-OPEN-BI-DIRECTIONAL-CONNECTION`
TTL Start	Node, Subnet, Interface	`AODV-TTL-START`
TTL Increment	Node, Subnet, Interface	`AODV-TTL-INCREMENT`
TTL Threshold	Node, Subnet, Interface	`AODV-TTL-THRESHOLD`
RREQs Replied by Destination Only	Node, Subnet, Interface	`AODV-DEST-ONLY-NODE`

Setting Parameters

- Set **Enable Hello Messages** to *Yes*, to specify whether hello messages will be used to maintain connectivity with neighbors.

- If **Enable Hello Messages** is set to *Yes*, then set the dependent parameters listed in Table 5-3.

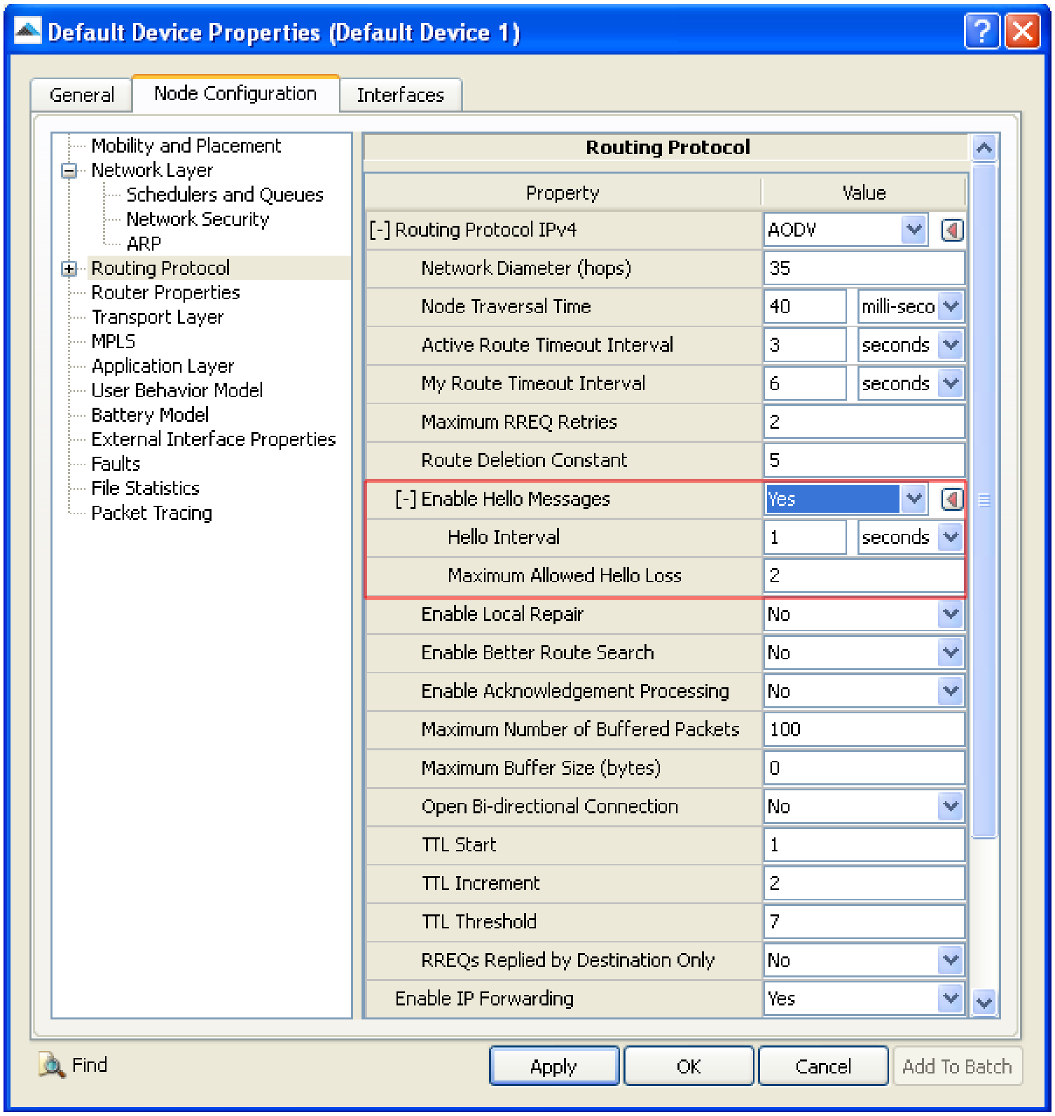


FIGURE 5-2. Setting Hello Message Parameters

TABLE 5-3. Command Line Equivalent of Hello Message Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Hello Interval	Node, Subnet, Interface	`AODV-HELLO-INTERVAL`
Maximum Allowed Hello Loss	Node, Subnet, Interface	`AODV-ALLOWED-HELLO-LOSS`

Configuring Statistics Parameters

Statistics for AODV can be collected at the global and node levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for routing protocols including AODV, check the box labeled **Routing** in the appropriate properties editor.

TABLE 5-4. Command Line Equivalent of Hello Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Routing	Global, Node	`ROUTING-STATISTICS`

Configuring Packet Tracing Parameters

Packet tracing for AODV be enabled at the global and node levels. To enable packet tracing for AODV addition to setting the AODV trace parameter, **Trace AODV**, several other trace parameters also need to be set. See Section 4.2.10 of *EXata User's Guide* for details of configuring packet tracing parameters.

TABLE 5-5. Command Line Equivalent of Packet Tracing Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Trace AODV	Global, Node	`TRACE-AODV`

5.1.5 Statistics

Table 5-6 shows the AODV statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 5-6. AODV Statistics

Statistic	Description
Number of RREQ Packets Initiated	Number of route request messages initiated.
Number of RREQ Packets Retried	Number of route requests resent because node did not receive a route reply.
Number of RREQ Packets Forwarded	Number of route request messages forwarded by intermediate nodes.
Number of RREQ Packets Initiated for local repair	Number of route requests initiated for local repair.
Number of RREQ Packets sent for alternate route	Number of route requests initiated for finding alternate routes.
Number of RREQ Packets received	Number of route requests received
Number of Duplicate RREQ Packets received	Number of duplicate route requests received
Number of RREQ Packets dropped due to ttl expiry	Number of route requests dropped due to TTL expiration.
Number of RREQ Packets discarded for blacklist	Number of route request dropped due to the previous hop been in black list table.
Number of RREQ Packets received by Destination	Number of route requests received by the destination.
Number of RREP Packets Initiated as Destination	Number of route replies initiated from the destination.
Number of RREP Packets Initiated as intermediate node	Number of route replies initiated as an intermediate hop.

TABLE 5-6. AODV Statistics (Continued)

Statistic	Description
Number of RREP Packets Forwarded	Number of route replies forwarded by intermediate hops.
Number of Gratuitous RREP Packets sent	Number of gratuitous route replies sent.
Number of RREP Packets Received	Number of route replies received by the node.
Number of RREP Packets Received for local repair	Number of route replies received for local repair.
Number of RREP Packets Received as Source	Number of route replies received as data source.
Number of Hello message sent	Number of hello messages sent.
Number of Hello message received	Number of hello message received.
Number of RERR Packets Initiated	Number of route error packets initiated.
Number of RERR Packets Initiated with N flag	Number of route error packets initiated with the N flag set.
Number of RERR Packets forwarded	Number of route error packets forwarded.
Number of RERR Packets forwarded with N flag	Number of route error packets forwarded with the N flag set.
Number of RERR Packets received	Number of route error packets received.
Number of RERR Packets received with N flag	Number of route error packets received with the N flag set.
Number of RERR Packets discarded	Number of route error packets discarded.
Number of Data packets sent as Source	Number of data packets sent as the source of the data.
Number of Data Packets Forwarded	Number of data packets forwarded.
Number of Data Packets Received	Number of data packets received as the destination of the data.
Number of Data Packets Dropped for no route	Number of data packets dropped due to lack of route.
Number of Data Packets Dropped for buffer overflow	Number of data packets dropped due to buffer overflow.
Number of Routes Selected	Number of routes added to the route cache.
Total Hop Counts for all routes	Aggregate sum of the hop counts of all routes added to the route cache.
Number of Packets Dropped for exceeding Maximum Hop Count	Number of data packets dropped because maximum hop count exceeded.
Number of times link broke	Number of times link is broken between nodes.

5.1.6 Sample Scenario

5.1.6.1 Scenario Description

Figure 5-3 shows an example of how you can use the AODV routing protocol in a scenario. This example is a six-node ad-hoc scenario with the Routing Protocol set to AODV. The application is configured between nodes 1 and 6, node 1 sends 100 packets to node 6, and each packet is 512 bytes.

FIGURE 5-3. Sample Scenario Topology

5.1.6.2 Command Line Configuration

In the configuration file, specify the following parameters.

```
ROUTING-PROTOCOL AODV
AODV-NET-DIAMETER 35
AODV-NODE-TRAVERSAL-TIME 40MS
AODV-ACTIVE-ROUTE-TIMEOUT 300MS
AODV-MY-ROUTE-TIMEOUT 600MS
AODV-HELLO-INTERVAL 1000MS
AODV-RREQ-RETRIES 2
AODV-ROUTE-DELETION-CONSTANT 5
AODV-PROCESS-HELLO NO
AODV-ALLOWED-HELLO-LOSS 2
AODV-LOCAL-REPAIR NO
AODV-SEARCH-BETTER-ROUTE NO
AODV-BUFFER-MAX-PACKET 100
AODV-BUFFER-MAX-BYTE 0
AODV-OPEN-BI-DIRECTIONAL-CONNECTION 1
AODV-TTL-START 1
AODV-TTL-INCREMENT 2
AODV-TTL-THRESHOLD 7
AODV-DEST-ONLY-NODE NO
```

5.1.6.3 GUI Configuration

To configure the sample scenario, perform the following steps:

1. Create a new scenario. Place six default nodes as shown in Figure 5-3.
2. Go to Table View and select all nodes.
3. Right click and open Group Default Device Properties Editor window.
4. To set routing protocol, go to Group Default Device Properties Editor **>** Node Configuration **>** Routing Protocol as shown in Figure 5-4.
5. Set **Routing Protocol IPv4** as *AODV* and set other AODV parameters as shown in Figure 5-4.

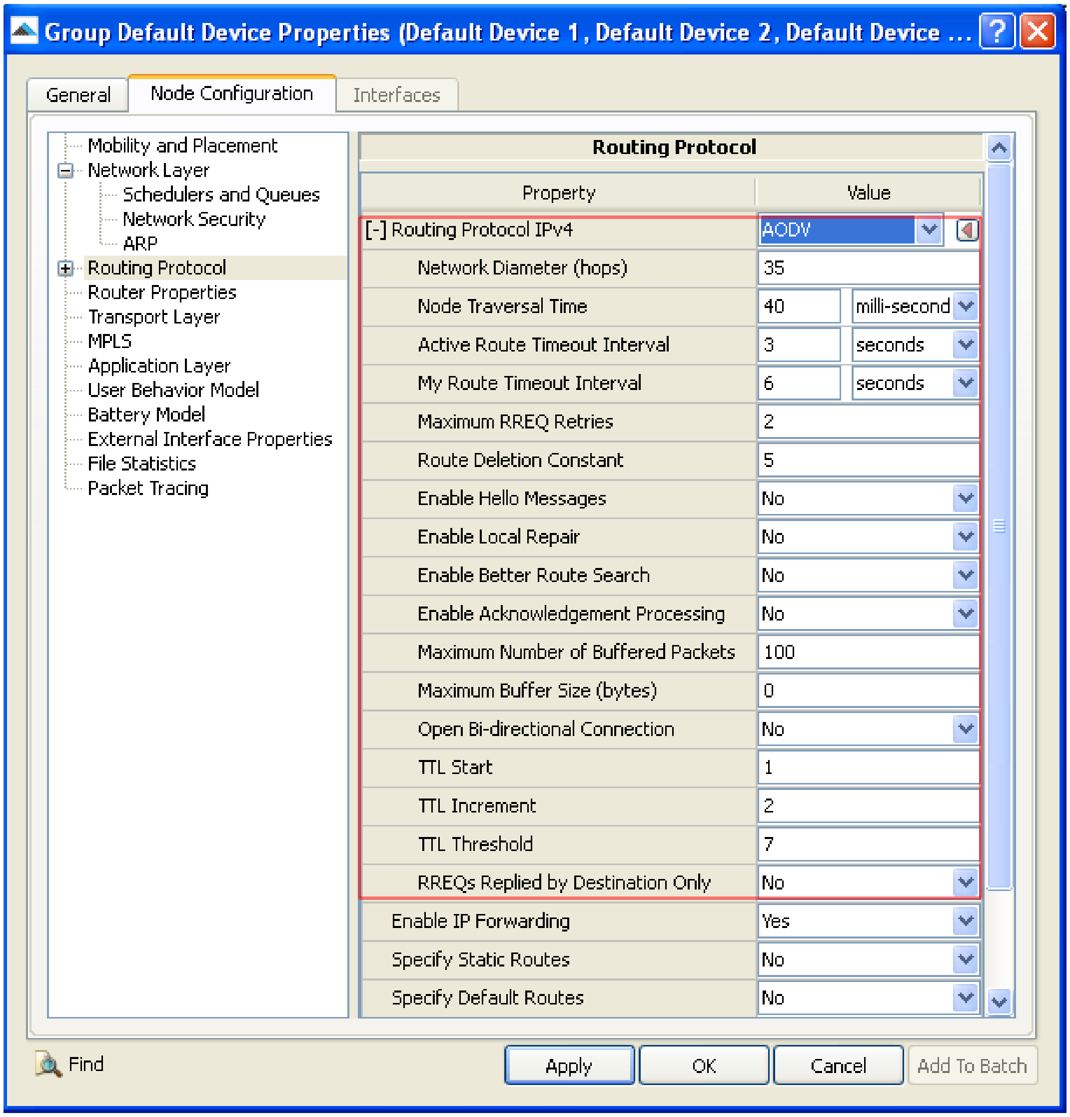


FIGURE 5-4. Configuring AODV for the Sample Scenario

6. Create a CBR application between node 1 and node 6.

5.1.7 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the AODV model. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/aodv. Table 5-7 lists the sub-directory where each scenario is located.

TABLE 5-7. AODV Scenarios Included in EXata

Scenario	Description
aodv-ipv4\generating-rrep\5-nodes	Shows RREP generation by intermediate node in a 5 node IPv4 network.
aodv-ipv4\generating-rrep\6-nodes	Shows RREP generation by destination node in a 6 node IPv4 network.

TABLE 5-7. AODV Scenarios Included in EXata (Continued)

Scenario	Description
aodv-ipv4\local-repair\find-best	Shows AODV operation during link break in an IPv4 network.
aodv-ipv4\local-repair\local-repair	Shows broken route being repaired locally in an IPv4 network.
aodv-ipv4\local-repair\no-local-repair	Shows broken route not been repaired locally in an IPv4 network.
aodv-ipv4\mixed-wired	Shows AODV operation in a wired IPv4 network.
aodv-ipv4\mixed-wireless	Shows AODV operation in a wired wireless (mixed) IPv4 network.
aodv-ipv4\ns3-wired	Shows AODV operation in a 3 node wired IPv4 network.
aodv-ipv4\ns3-wireless	Shows AODV operation in a 3 node wireless IPv4 network.
aodv-ipv4\ns5-wired	Shows AODV operation in a 5 node wired IPv4 network.
aodv-ipv4\ns5-wireless	Shows AODV operation in a 5 node wireless IPv4 network.
aodv-ipv4\processing-rrep	Shows handling of RREP in an IPv4 network.
aodv-ipv4\processing-rreq\5-nodes	Shows handling of RREQ in a 5 node IPv4 network.
aodv-ipv4\processing-rreq\6-nodes	Shows handling of RREQ in a 6 node IPv4 network.
aodv-ipv4\processing-rreq\string	Shows hop-count update in a 6 node IPv4 network.
aodv-ipv4\route-errors\6-node-partition	Shows RERR generation and processing in a 6 node IPv4 network.
aodv-ipv4\route-errors\7-node-partition	Shows RERR generation and processing in a 7 node IPv4 network.
aodv-ipv4\route-errors\mobile	Shows sequence number update when an alternate path is found to the same destination in an IPv4 network.
aodv-ipv6\dualip	Shows AODV operation in dual-IP network.
aodv-ipv6\generating-rrep\5-nodes	Shows RREP generation by intermediate node in a 5 node IPv6 network.
aodv-ipv6\generating-rrep\6-nodes	Shows RREP generation by destination node in a 6 node IPv6 network.
aodv-ipv6\local-repair\find-best	Shows AODV operation during link break in an IPv6 network.
aodv-ipv6\local-repair\local-repair	Shows broken route being repaired locally in an IPv6 network.
aodv-ipv6\local-repair\no-local-repair	Shows broken route not been repaired locally in an IPv6 network.
aodv-ipv6\mixed-wired	Shows AODV operation in a wired IPv6 network.
aodv-ipv6\mixed-wireless	Shows AODV operation in a wired wireless (mixed) IPv6 network.
aodv-ipv6\ns3-wired	Shows AODV operation in a 3 node wired IPv6 network.
aodv-ipv6\ns3-wireless	Shows AODV operation in a 3 node wireless IPv6 network.
aodv-ipv6\ns5-wired	Shows AODV operation in a 5 node wired IPv6 network.
aodv-ipv6\ns5-wireless	Shows AODV operation in a 5 node wireless IPv6 network.
aodv-ipv6\processing-rrep	Shows handling of RREP in an IPv6 network.
aodv-ipv6\processing-rreq\5-nodes	Shows handling of RREQ in a 5 node IPv6 network.
aodv-ipv6\processing-rreq\6-nodes	Shows handling of RREQ in a 6 node IPv6 network.
aodv-ipv6\processing-rreq\string	Shows hop-count update in a 6 node IPv6 network.
aodv-ipv6\route-errors\6-node-partition	Shows RERR generation and processing in a 6 node IPv6 network.
aodv-ipv6\route-errors\7-node-partition	Shows RERR generation and processing in a 7 node IPv6 network
aodv-ipv6\route-errors\mobile	Shows sequence number update when an alternate path is found to the same destination in an IPv6 network.

5.1.8 References

1. RFC 3561, “Ad hoc On-Demand Distance Vector (AODV) Routing.” C. Perkins, E. Belding-Royer, S. Das. July 2003.
2. IETF draft < draft-perkins-manet-aodv6-01.txt>, “Ad hoc On-Demand Distance Vector (AODV) Routing for IP version 6.” C. Perkins, E. Royer, S. Das. Nov 2000.

5.2 Bordercast Resolution Protocol (BRP)

The EXata BRP model is based on the draft-ietf-manet-zone-brp-02.

5.2.1 Description

BRP is a component of Zone Routing Protocol (ZRP). It is used to efficiently flood broadcast packets throughout the network. It is not a full-featured routing protocol.

5.2.2 Command Line Configuration

BRP is automatically enabled if Zone Routing Protocol (ZRP) is specified as the routing protocol. To specify ZRP as the routing protocol, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]  ROUTING-PROTOCOL      ZRP
```

The scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

BRP Parameters

There are no additional configuration parameters for the BRP model.

5.2.3 GUI Configuration

This section describes how to configure BRP in the GUI.

Configuring BRP Parameters

To configure the BRP parameters, perform the following steps:

1. Go to one of the following locations:
   - To set properties for a specific wireless subnet, go to **Wireless Subnet Properties Editor > Routing Protocol > General**.
   - To set properties for a specific node, go to **Default Device Properties Editor > Node Configuration > Routing Protocol**.
   - To set properties for a specific interface of a node, go to one of the following locations:
     - **Interface Properties Editor > Interfaces > Interface # > Routing Protocol**.
     - **Default Device Properties Editor > Interfaces > Interface # > Routing Protocol**.

In this section, we show how to configure BRP parameters for a specific node using the Default Device Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **Routing Protocol IPv4** to *ZRP*.
3. Set **IERP Uses BRP** to *Yes*.

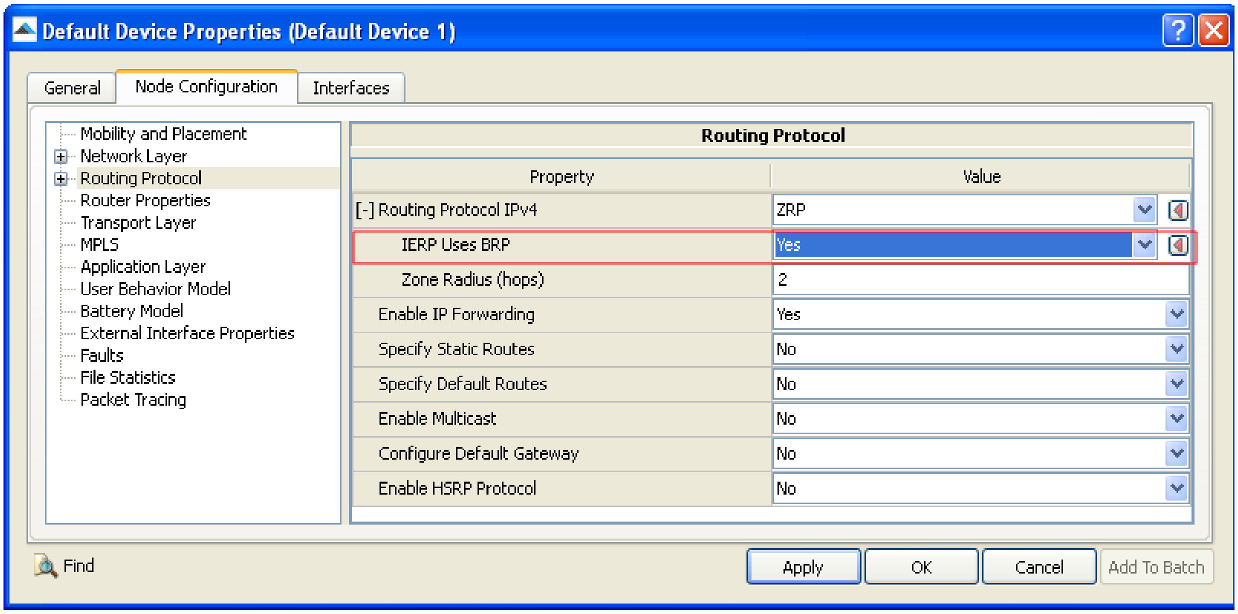


FIGURE 5-5. Setting BRP Parameters

Configuring Statistics Parameters

Statistics for BRP can be collected at the global and node levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for routing protocols including BRP, check the box labeled **Routing** in the appropriate properties editor.

TABLE 5-8. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Routing	Global, Node	ROUTING-STATISTICS

5.2.4 Statistics

Table 5-9 shows the BRP statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 5-9. BRP Statistics

Statistic	Description
Number of query packets sent	Number of BRP query packets sent by the node.
Number of query packets received	Number of BRP query packets received by the node.

5.2.5 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the BRP model. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/zrp/routing-thru-ierp-brp. Table 5-10 lists the sub-directory where each scenario is located.

TABLE 5-10. BRP Scenarios Included in EXata

Scenario Sub-directory	Description
brp-query	Shows whether the node gets the query packet.
search-own-zone	Shows whether the source node searches its own routing zone first.
zone-radius-increase	Shows whether the node generates an IERP query packet in addition to relaying the query packet and checking the zone radius.

5.2.6 References

1. Draft-ietf-manet-zone-brp-02. "The Bordercast Resolution Protocol (BRP) for Ad Hoc Networks." Zygmunt J. Haas, Marc R. Pearlman, Prince Samar. July 2002.

5.3 Dynamic MANET On-demand (DYMO) Routing Protocol

The EXata Dynamic MANET On-demand (DYMO) protocol is based on draft-ietf-manet-dymo-09.

5.3.1 Description

The Dynamic MANET On-demand (DYMO) routing protocol is a unicast reactive routing protocol which is intended for used by mobile nodes in wireless multihop networks. DYMO is a reactive routing protocol. In this Routing Message (Control Packet) is generated only when the node receives a data packet and it does not have any routing information. The basic operation of DYMO protocol is route discovery and route management.

During route discovery, the Route Request (RREQ) routing message is generated for a target node for which it does not have any routing formation. Source node floods the RREQ message to find the target node. During flooding each intermediate node records a route to the originating node by adding the routing information into this routing table. When the target node receives the RREQ, it responds with a Route Reply (RREP) mesage which is sent as a unicast message toward the originating node. Each node that receives the RREP records a route to the target node and forwards the RREP to next hop. When the originating node receives the RREP, routes have been established between the originating node and the target node in both directions. In order to react to the changes in the network topology nodes maintain their routes and monitor their links. A Route Error (RERR) message is generated by a node whenever it receives a data packet for a destination to which it has no route in its routing table. This RERR RM notifies other nodes that the current route is broken. Once the source receives the RERR, it re-initiates route discovery if it still has packets to deliver. Hello Messages can be used by nodes to maintain routes to all its neighboring nodes. Sequence numbers are used to avoid routing loops and propagation of stale routing information.

5.3.2 Features and Assumptions

This section describes the implemented features, omitted features, assumptions and limitations of the DYMO model.

5.3.2.1 Implemented Features

- Support for both IPv4 and IPv6 networks.
- Internet attachment and gateway.
- Routing Message (RM) generation and processing.
- Route error (RERR) generation and processing.
- Link/Neighbor Discovery and Monitoring using link layer feedback and Hello message broadcasting
- Sequence number maintenance, increment, rollover etc.
- Support for multiple interfaces.
- RREP and gratuitous RREP packets generation by intermediate nodes. (configurable option).
- DYMO route time outs, including DYMO_USED_ROUTE_TIMEOUT, DYMO_NEW_ROUTE_TIMEOUT, and DYMO_DELETE_ROUTE_TIMEOUT.
- The nodes relaying RREQ and RREP packets can append its own address (hopCnt, seqNum) in the relayed RREQ/RREP packets (configurable option).
- RERR message include all unreachable addresses (configurable option).

5.3.2.2 Omitted Features

- Advertising PREFIX_LENGTH tlv.

5.3.2.3 Assumptions and Limitations

- DYMO_MIN_ROUTE_TIMEOUT is being modeled by requiring that the DYMO_NEW_ROUTE_TIMEOUT and DYMO_DELETE_ROUTE_TIMEOUT are greater than DYMO_NET_TRAVERSAL_TIME

5.3.3 Command Line Configuration

To select DYMO as the routing protocol, include the following parameter(s) in the scenario configuration (.config) file:

- For an IPv4 node, use the following parameter:

```
[<Qualifier>] ROUTING-PROTOCOL          DYMO
```

- For an IPv6 node, use *either* of the following parameters:

```
[<Qualifier>] ROUTING-PROTOCOL          DYMO
```

or

```
[<Qualifier>] ROUTING-PROTOCOL-IPv6     DYMO
```

- For a dual IP-node, use *both* the following parameters:

```
[<Qualifier>] ROUTING-PROTOCOL          DYMO
```

and

```
[<Qualifier>] ROUTING-PROTOCOL-IPv6     DYMO
```

The scope of these parameter declarations can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

DYMO Parameters

Table 5-11 describes the DYMO parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 5-11. DYMO Parameters

Parameter	Value	Description
`DYMO-MAX-HOP-LIMIT` *Optional* *Scope:* All	Integer *Range:* `> 0` *Default:* `0`	Specifies the maximum possible number of hops between two nodes communication with each other in the DYMO network.
`DYMO-NODE-TRAVERSAL-TIME` *Optional* *Scope:* All	Time *Range:* `> 0S` *Default:* `90MS`	Specifies the conservative estimate of the average one-hop traversal time for packets and should include queuing, transmission, propagation and other delays.
`DYMO-NEW-ROUTE-TIMEOUT` *Optional* *Scope:* All	Time *Range:* `> 0S` *Default:* `5000MS`	Specifies the timeout time for a new route. After the expiration of this timer, the route is set to delete after `DYMO-DELETE-ROUTE-TIMEOUT` time period.

TABLE 5-11. DYMO Parameters (Continued)

Parameter	Value	Description
`DYMO-USED-ROUTE-TIMEOUT` *Optional* *Scope:* All:	Time *Range:* `> 0S` *Default:* `5000MS`	Specifies the timeout time for an active route; each time a route is used, the lifetime of that route is updated by this value.
`DYMO-DELETE-ROUTE-TIMEOUT` *Optional* *Scope:* All	Time *Range:* `> 0S` *Default:* See description	Specifies the time interval for which a route, after been flagged as inactive, remains in the routing table before been deleted. **Note:** This parameter should be set such that `DYMO-NEW-ROUTE-TIMEOUT` + `DYMO-DELETE-ROUTE-TIMEOUT` ≥ `DYMO-NET-TRAVERSAL-TIME` **Note:** The default value is the larger of `10S` and `DYMO-ALLOWED-HELLO-LOSS` * `DYMO-HELLO-INTERVAL`.
`DYMO-HELLO-INTERVAL` *Optional* *Scope:* All	Time *Range:* `> 0S` *Default:* `100MS`	Specifies the time interval for which a node waits to broadcast the next hello message. **Note:** This parameter is applicable only if `DYMO-PROCESS-HELLO` is set to `YES`.
`DYMO-ALLOWED-HELLO-LOSS` *Optional* *Scope:* All	Integer *Range:* `> 0` *Default:* `4`	Specifies the number of hello intervals to wait before flagging the neighboring link as broken. **Note:** This parameter is applicable only if `DYMO-PROCESS-HELLO` is set to `YES`.
`DYMO-RREQ-RETRIES` Optional *Scope:* All	Integer *Range:* `> 0` *Default:* `3`	Specifies the maximum number of times expanded ring search for a destination will be repeated if no route was found during previous attempts.
`DYMO-PROCESS-HELLO` *Optional* *Scope:* All	List: • `YES` • `NO` *Default:* `NO`	Specifies whether hello messages will be used to maintain connectivity with neighbors.
`DYMO-BUFFER-MAX-PACKET` *Optional* *Scope:* All	Integer *Range:* `> 0` *Default:* `50` *Unit:* packets	Specifies the maximum number of packets DYMO buffer can hold at any given time irrespective of the packet size.
`DYMO-BUFFER-MAX-BYTE` *Optional* *Scope:* All	Integer *Range:* `> 0` *Default:* `0` *Unit:* bytes	Specifies the maximum size of DYMO buffer in bytes. If no value or zero is specified to this parameter, `DYMO-BUFFER-MAX-PACKET` will be used to determine the size of the buffer.

TABLE 5-11. DYMO Parameters (Continued)

Parameter	Value	Description
`DYMO-TTL-START` *Optional* *Scope:* All	Integer *Range:* `> 0` *Default:* `1`	Specifies the number of hops a route request message will traverse in search for a destination while initiating a route request.
`DYMO-TTL-INCREMENT` *Optional* *Scope:* All	Integer *Range:* `> 0` *Default:* `2`	Specifies the value by which the TTL is incremented, each time a request is transmitted.
`DYMO-TTL-THRESHOLD` *Optional* *Scope:* All	Integer *Range:* `> 0` *Default:* `7`	Specifies the TTL value up to which `DYMO-TTL-INCREMENT` will be used to increment the TTL. After this value, `DYMO-MAX-HOP-LIMIT` will used as the TTL.
`DYMO-DEST-ONLY-NODE` *Optional* *Scope:* All	List: • `YES` • `NO` *Default:* `NO`	Specifies whether intermediate nodes having route to the destination will respond to an incoming RREQ. If set to `YES`, only destination nodes will respond to an RREQ.
`DYMO-APPEND-SELF-ADDRESS` *Optional* *Scope:* All	List: • `YES` • `NO` *Default:* `YES`	Specifies whether the node will append its own address to the relayed request/reply message.
`DYMO-INCREASE-SEQ-NUM-IN-APPENDING` *Optional* *Scope:* All	List: • `YES` • `NO` *Default:* `YES`	Specifies whether the node will increment its sequence number prior to appending its own address to the request/reply message.
`DYMO-RERR-INCLUDE-ALL-UNREACHABLES` Optional *Scope:* All	List: • `YES` • `NO` *Default:* `YES`	Specifies whether other unreachable addresses which use the same unavailable link should be added to the RERR message.
`DYMO-GATEWAY` *Optional* *Scope:* Node, Interface *Instances:* No	List: • `YES` • `NO` *Default:* `NO`	Specifies whether this node/interface is configured as gateway.

TABLE 5-11. DYMO Parameters (Continued)

Parameter	Value	Description
`DYMO-GATEWAY-PREFIX-LENGTH` Optional *Scope:* Node, Interface *Instances:* No	Integer *Range:* `> 0` *Default:* `24` (for IPv4) `64` (for IPv6)	Specifies the number of bits used in prefix filter of the DYMO subnet(s) attached to the gateway. **Note:** This parameter is applicable only if `DYMO-GATEWAY` is set to `YES`.
`ROUTING-STATISTICS` Optional *Scope:* Global, Node	List: • `YES` • `NO` *Default:* `YES`	Indicates whether statistics are collected for routing protocols, including DYMO.
`TRACE-DYMO` Optional *Scope:* Global, Node	List: • `YES` • `NO` *Default:* `NO`	Indicates whether packet tracing is enabled for DYMO. **Note:** To enable packet tracing, some other parameters need to be configured as well. Refer to Section 4.2.10 of *EXata User's Guide* for details.

5.3.4 GUI Configuration

This section describes how to configure DYMO in the GUI.

Configuring DYMO Parameters

To configure the DYMO parameters, perform the following steps:

1. Go to one of the following locations:
   - To set properties for a specific wireless subnet, go to **Wireless Subnet Properties Editor > Routing Protocol > General**.
   - To set properties for a specific wired subnet, go to **Wired Subnet Properties Editor > Routing Protocol > General**.
   - To set properties for a specific point-to-point link, go to **Point-to-point Link Properties Editor > Point-to-point Link Properties > Routing Protocol**.
   - To set properties for a specific node, go to **Default Device Properties Editor > Node Configuration > Routing Protocol**.
   - To set properties for a specific interface of a node, go to one of the following locations:
     - **Interface Properties Editor > Interfaces > Interface # > Routing Protocol**.
     - **Default Device Properties Editor > Interfaces > Interface # > Routing Protocol**.

In this section, we show how to configure DYMO parameters for a specific node using the Default Device Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **Routing Protocol IPv4** (or **Routing Protocol IPv6**) to *DYMO* and set the dependent parameters listed in Table 5-12.

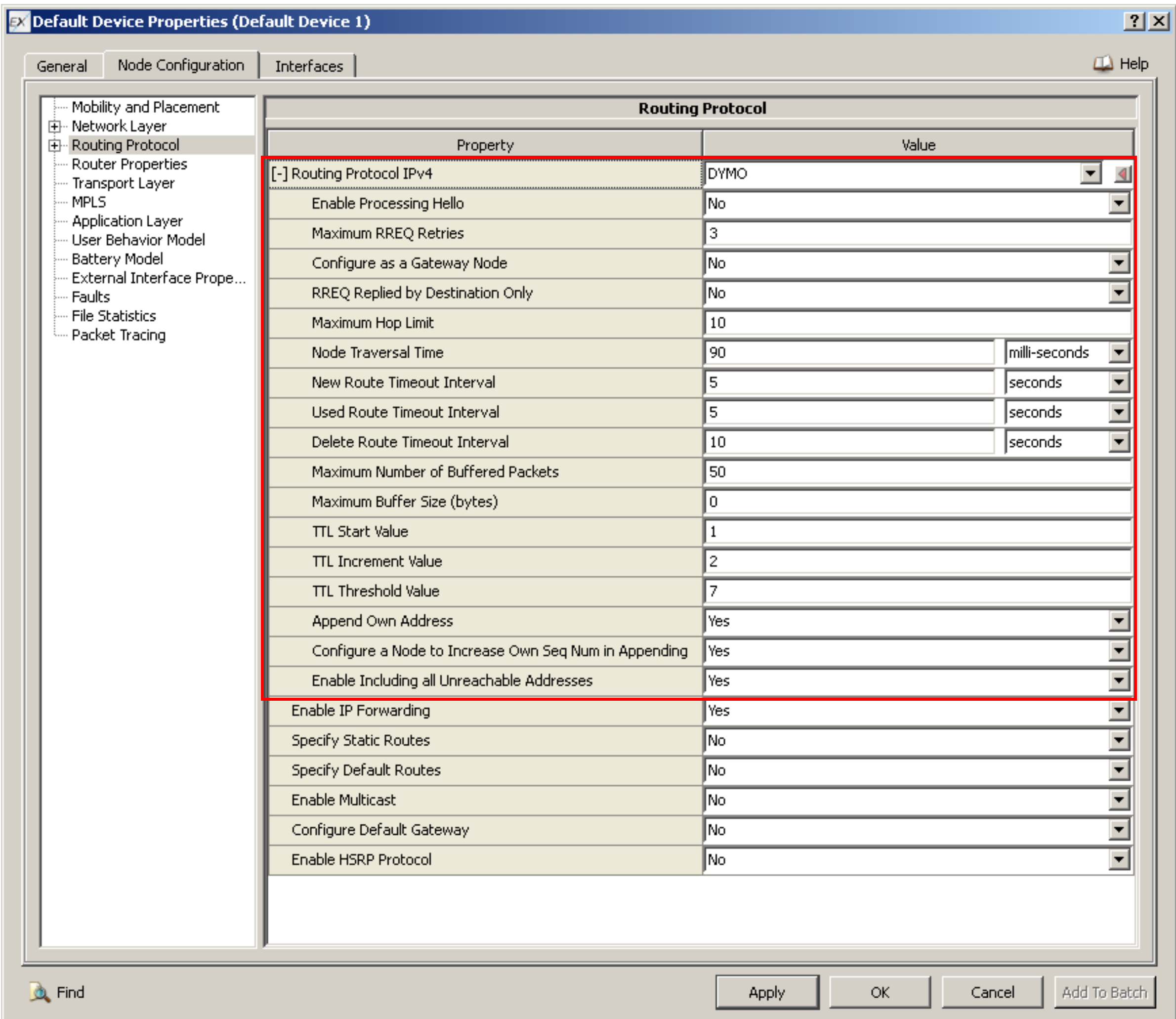


FIGURE 5-6. Setting DYMO Parameters

TABLE 5-12. Command Line Equivalent of DYMO Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Enable Processing Hello	Node, Subnet, Interface	`DYMO-PROCESS-HELLO`
Maximum RREQ Retries	Node, Subnet, Interface	`DYMO-RREQ-RETRIES`
Configure as a Gateway Node	Node, Interface	`DYMO-GATEWAY`
RREQ Replied By Destination Only	Node, Subnet, Interface	`DYMO-DEST-ONLY-NODE`

TABLE 5-12. Command Line Equivalent of DYMO Parameters (Continued)

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Maximum Hop Limit	Node, Subnet, Interface	`DYMO-MAX-HOP-LIMIT`
Node Traversal Time	Node, Subnet, Interface	`DYMO-NODE-TRAVERSAL-TIME`
New Route Timeout Interval	Node, Subnet, Interface	`DYMO-NEW-ROUTE-TIMEOUT`
Used Route Timeout Interval	Node, Subnet, Interface	`DYMO-USED-ROUTE-TIMEOUT`
Delete Route Timeout interval	Node, Subnet, Interface	`DYMO-DELETE-ROUTE-TIMEOUT`
Maximum Numbers of Buffer packets	Node, Subnet, Interface	`DYMO-BUFFER-MAX-PACKET`
Maximum Buffer Size (bytes)	Node, Subnet, Interface	`DYMO-BUFFER-MAX-BYTE`
TTL Start Value	Node, Subnet, Interface	`DYMO-TTL-START`
TTL increment Value	Node, Subnet, Interface	`DYMO-TTL-INCREMENT`
TTL Threshold Value	Node, Subnet, Interface	`DYMO-TTL-THRESHOLD`
Append Own Address	Node, Subnet, Interface	`DYMO-APPEND-SELF-ADDRESS`
Configure a Node to Increase Own Seq Num in Appending	Node, Subnet, Interface	`DYMO-INCREASE-SEQ-NUM-IN-APPENDING`
Enable Including All Unreachable Addresses	Node, Subnet, Interface	`DYMO-RERR-INCLUDE-ALL-UNREACHABLES`

Setting Parameters

- To enable Hello processing, set **Enable Processing Hello** to *Yes;* otherwise, set **Enable Processing Hello** to *No*.
- To configure node as DYMO gateway set **Configure as a Gateway Node** to *Yes*; otherwise, set **Configure as a Gateway Node** to *No*.

3. If **Enable Processing Hello** is set to *Yes*, then set the dependent parameters listed in Table 5-13.

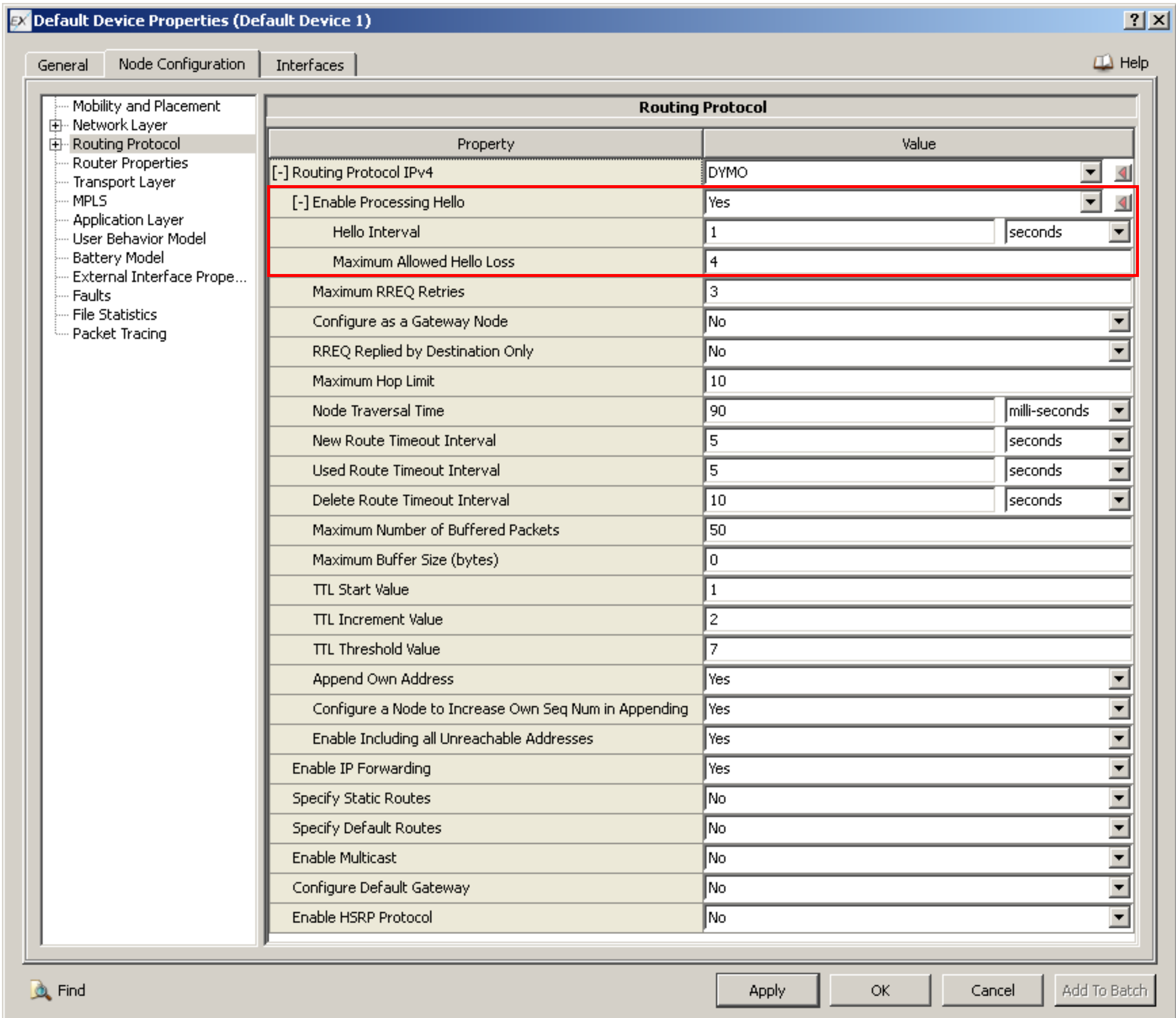


FIGURE 5-7. Setting Hello Processing-specific Parameters

TABLE 5-13. Command Line Equivalent of Hello Processing-specific Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Hello Interval	Node, Subnet, Interface	`DYMO-HELLO-INTERVAL`
Maximum Allowed Hello Loss	Node, Subnet, Interface	`DYMO-ALLOWED-HELLO-LOSS`

4. If **Configure as a Gateway Node** is set to *Yes*, then set the dependent parameters listed in Table 5-14.

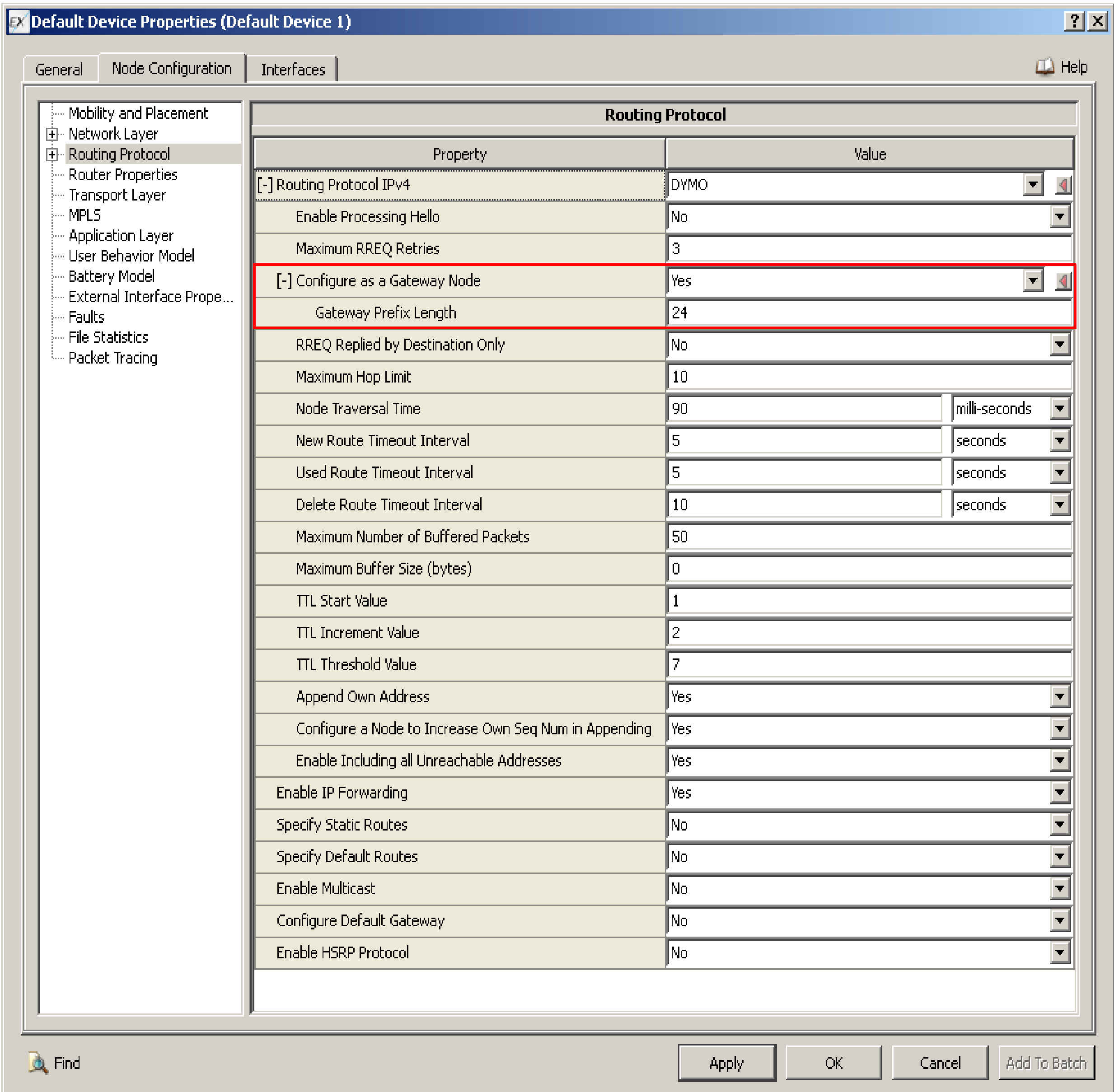


FIGURE 5-8. Setting Gateway Node-specific Parameters

TABLE 5-14. Command Line Equivalent of Gateway Node-specific Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Gateway Prefix Length	Node, Subnet, Interface	`DYMO-GATEWAY-PREFIX-LENGTH`

Configuring Statistics Parameters

Statistics for DYMO can be collected at the global and node levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for routing protocols including DYMO, check the box labeled **Routing** in the appropriate properties editor.

TABLE 5-15. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Routing	Global, Node	`ROUTING-STATISTICS`

Configuring Packet Tracing Parameters

Packet tracing for DYMO can be enabled at the global and node levels. To enable packet tracing for DYMO, in addition to setting the DYMO trace parameter, **Trace DYMO**, several other trace parameters also need to be set. See Section 4.2.10 of *EXata User's Guide* for details of configuring packet tracing parameters.

TABLE 5-16. Command Line Equivalent of Packet Tracing Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Trace DYMO	Global, Node	`TRACE-DYMO`

5.3.5 Statistics

Table 5-17 shows the DYMO statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 5-17. DYMO Statistics

Statistic	Description
Number of RREQ Initiated	Total number of route request messages initiated.
Number of RREQ Retried	Total number of route request messages retried.
Number of RREQ Forwarded	Total number of route request messages forwarded.
Number of RREQ Received	Total number of route request messages received.
Number of Duplicate RREQ Received	Total number of duplicate route request messages received.
Number of RREQ TTL expired	Total number of route request TTLs (Time To Live) expired.
Number of RREQ Received by Target	Total number of route request messages received by target.
Number of RREP Initiated as Target	Total number of route reply messages initiated as target.
Number of RREP Forwarded	Total number of route reply messages forwarded.
Number of RREP Received	Total number of route reply messages received.

TABLE 5-17. DYMO Statistics (Continued)

Statistic	Description
Number of RREP Received as Target	Total number of route reply messages received as target.
Number of Hello message Sent	Total number of Hello messages sent.
Number of Hello message received	Total number of Hello messages received.
Number of RERR Initiated	Total number of route error messages initiated.
Number of RERR Forwarded	Total number of route error messages forwarded.
Number of RERR Received	Total number of route error messages received.
Number of RERR Discarded	Total number of route error messages discarded.
Number of Data packets sent as originator	Total number of data packets sent as originator.
Number of Data Packets Forwarded	Total number of data packets forwarded.
Number of Data Packets Received	Total number of data packets received.
Number of Data Packets Dropped for Buffer Overflow	Total number of data packets dropped for buffer overflow.
Number of Times Link Broken	Total number of times link failed.
Number of RREP Initiated as Intermediate	Total number of route reply messages initiated as intermediate.
Number of Gratuitous RREP Sent	Total number of gratuitous route reply messages sent.
Number of Data Packets Dropped for No Route	Total number of data packets dropped for no route.

5.3.6 Sample Scenario

5.3.6.1 Scenario Description

The topology of the sample scenario is shown in Figure 5-9. It is a seven-node scenario with the routing protocol set to DYMO from node 1 to 5. Nodes 3 and 6 and nodes 6 and 7 are connected through wired links and use static routes. Node 3 is the gateway node.

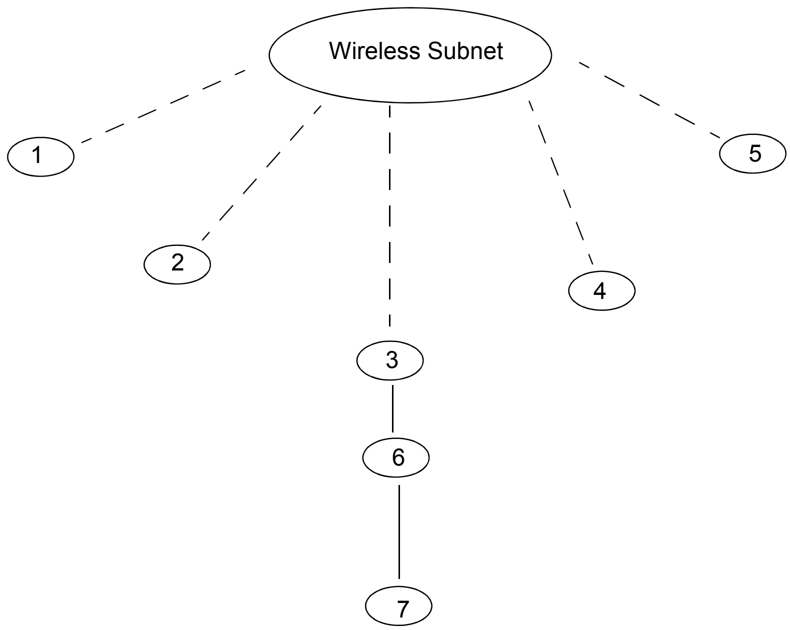


FIGURE 5-9. Topology of Sample Scenario

5.3.6.2 Command Line Configuration

Specify the following parameters in the scenario configuration (.config) file:

```
# The scenario is executed for a simulation time of 10 minutes
SIMULATION-TIME 10M

# 5 nodes are placed in an ad-hoc wireless subnet
SUBNET N8-192.0.0.0 { 1 thru 5 }

LINK N8-192.0.1.0 { 3, 6 }
[ 192.0.1.1 192.0.1.2 ] LINK-MAC-PROTOCOL ABSTRACT
[ 192.0.1.1 192.0.1.2 ] LINK-PHY-TYPE WIRED

LINK N8-192.0.2.0 { 6, 7 }
[ 192.0.2.1 192.0.2.2 ] LINK-MAC-PROTOCOL ABSTRACT
[ 192.0.2.1 192.0.2.2 ] LINK-PHY-TYPE WIRED

# At Node level: routing protocol is configured as DYMO on nodes 1 to 5
[ 1 thru 5 ] ROUTING-PROTOCOL DYMO

# At Node level: configuring node 3 as DYMO gateway
[ 3 ] DYMO-GATEWAY YES
[ 3 ] DYMO-GATEWAY-PREFIX-LENGTH 24

# At Node level: configuring static routes on nodes 3, 6, and 7
[ 3 6 7 ] STATIC-ROUTE YES
[ 3 6 7 ] STATIC-ROUTE-FILE sample.scenario.routes-static

# At Node level: routing protocol is configured as None for node 6, 7
[6 7 ] ROUTING-PROTOCOL NONE

# Note: All other parameters should be considered with default values.
```

Include the following lines in the sample.sceanrio.routes-static file:

```
3  N8-192.0.2.0  192.0.1.2
6  N8-192.0.0.0  192.0.1.1
7  N8-192.0.0.0  192.0.2.1
```

5.3.6.3 GUI Configuration

Follow these steps to configure the sample scenario in the GUI:

1. Create a new scenario. Place seven default nodes as shown in topology.
2. Place a wireless subnet and connect nodes 1 through 5 to the wireless subnet.
3. Connect nodes 3 and 6 and nodes 6 and 7 by wired links.
4. Go to Table View and select nodes 6 and 7.
5. Right-click and open Group Default Device Properties Editor window.
6. To set routing protocol, go to **Group Default Device Properties Editor > Node Configuration > Routing Protocol**.
7. Set **Routing Protocol IPv4** as *None*.

8. Similarly, set **Routing Protocol IPv4** as *DYMO* for node 1 thru 5.

9. Configure the required configurations parameters of DYMO as shown in Figure 5-10.

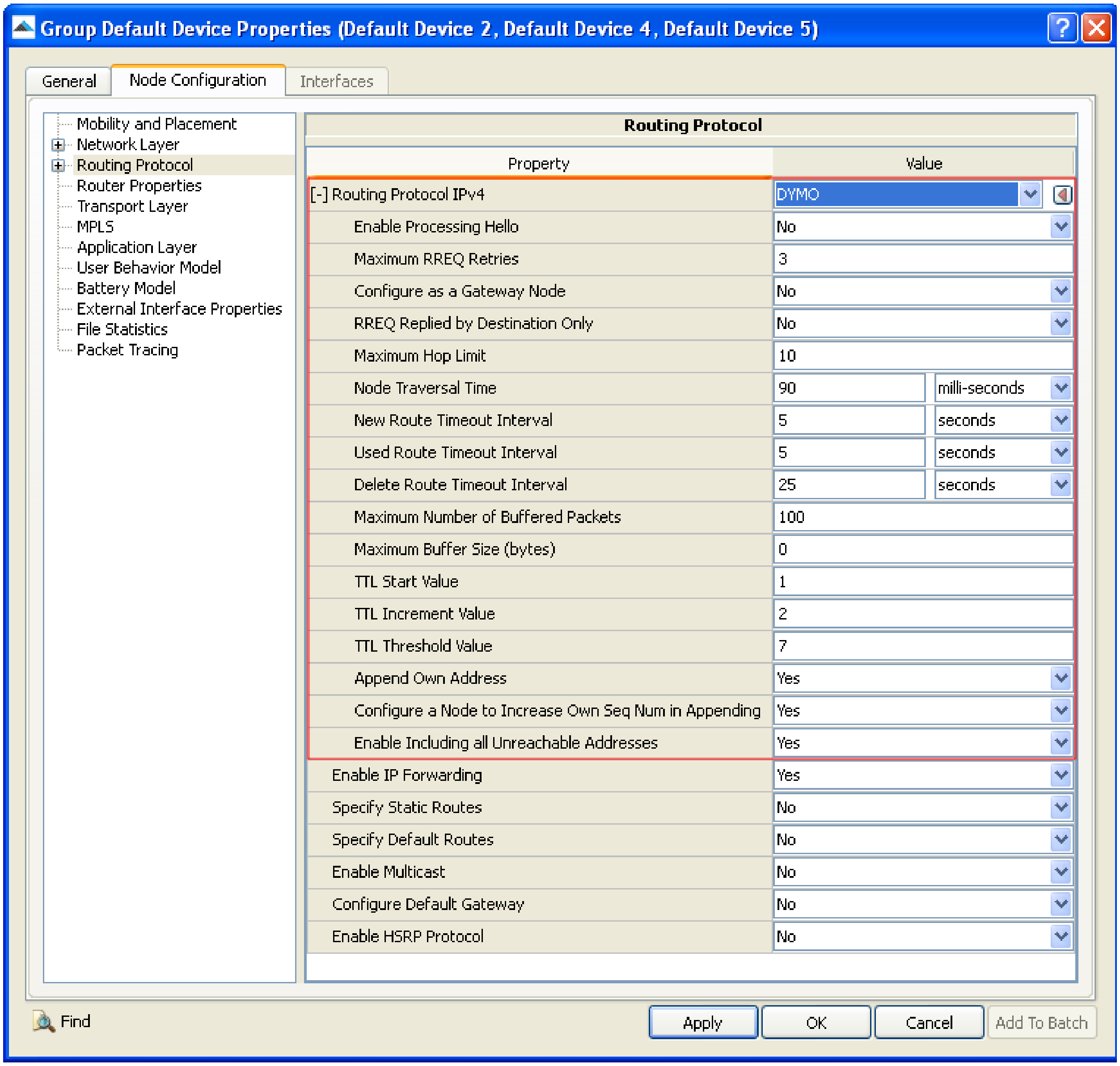


FIGURE 5-10. Setting Routing Protocol for Multiple Nodes.

Configuring DYMO Gateway

To configure node 3 as DYMO Gateway, go to **Default Device Properties Editor > Node Configuration > Routing Protocol** as set **Configure as Gateway Node** to *Yes*.

Adding Static Routes

Follow these steps to add static routes.

1. Go to Table View and select nodes 3, 6 and 7.
2. Right-click and open Group Default Device Properties Editor window.
3. Go to **Group Default Device Properties Editor > Node Configuration > Routing Protocol**.
4. Set **Specify Static Routes** to *Yes* and specify **Static Route File** as shown in Figure 5-11.

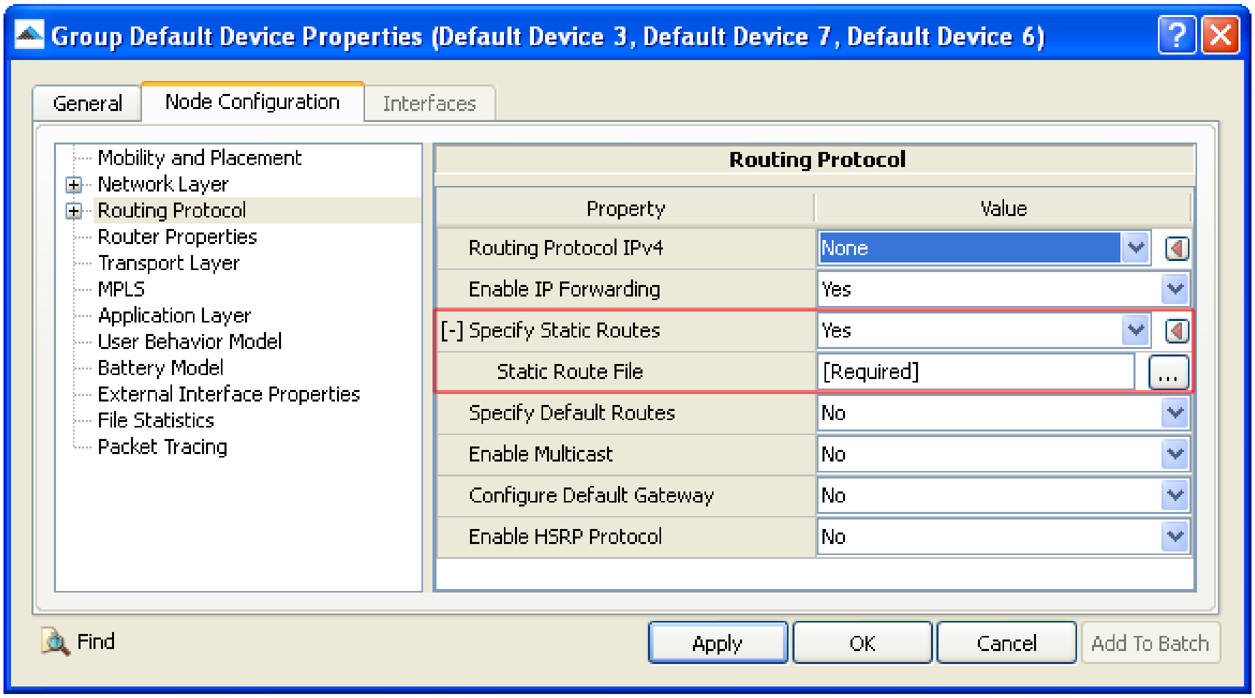


FIGURE 5-11. Adding Static Routes

5.3.7 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the DYMO model. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/dymo. Table 5-18 lists the sub-directory where each scenario is located.

TABLE 5-18. DYMO Scenarios Included in EXata

Scenario	Description
ipv4\dymo-rerr-generation	Shows RERR generation in an IPv4 network.
ipv4\Gateway-implementation	Shows working of a DYMO gateway in an IPv4 network.
ipv4\hello_msg	Shows hello message generation and processing in an IPv4 network.
ipv4\mixed-wired	Shows DYMO operation in an IPv4 network with two wireless subnets and wired links.
ipv4\mixed-wireless	Shows DYMO operation in an IPv4 network with a wireless subnet and wired links.
ipv4\route_discovery	Shows RREQ generation and reception in an IPv4 network.
ipv4\route_error	Shows RERR generation and reception in an IPv4 network.

TABLE 5-18. DYMO Scenarios Included in EXata (Continued)

Scenario	Description
ipv4\rreq-rrep-initiation	Shows DYMO operation in a multiple subnet IPv4 network.
ipv4-ipv6-ipv4	Shows DYMO operation in a dual-IP network
ipv6-ipv4-ipv6	Shows DYMO operation in a dual-IP network.
ipv6\Gateway-Implementation	Shows working of a DYMO gateway in an IPv6 network.
ipv6\hello_msg	Shows hello message generation and processing in an IPv6 network.
ipv6\mixed-wired	Shows DYMO operation in an IPv6 network with two wireless subnets and wired links.
ipv6\route_discovery	Shows RREQ generation and reception in an IPv6 network.
ipv6\route_error	Shows RERR generation and reception in an IPv6 network.
ipv6\mixed-wireless	Shows DYMO operation in an IPv6 network with a wireless subnet and wired links.

5.3.8 References

1. IETF draft <draft-ietf-manet-dymo-09>, "Dynamic MANET On-demand (DYMO) Routing", C. Perkins, I. Chakeres. May 2007.
2. IETF draft <draft-ietf-manet-packetbb-03>, "Generalized MANET Packet/Message Format", T. Clausen, C. Dearlove, J. Dean, C. Adjih. January 2007.
3. IETF draft <draft-ietf-manet-nhdp-04>, “MANET Neighborhood Discovery Protocol (NHDP)", T. Clausen, C. Dearlove, J. Dean. June 2007.

5.4 Dynamic Source Routing (DSR) Protocol

The EXata DSR Model is based on the draft-ietf-manet-dsr-07.txt.

5.4.1 Description

Dynamic Source Routing (DSR) is an on-demand routing protocol that is specifically designed for use in multi-hop wireless ad hoc networks of mobile nodes. DSR builds routes only on-demand by flooding Route Request packets if a sender wishes to send data to a destination with no known route. In addition to the on-demand algorithm, DSR implements a set of optimizations to attempt to route packets more efficiently, and reduce the control overhead.

5.4.2 Features and Assumptions

This section describes the implemented features, omitted features, assumptions and limitations of the DSR model.

5.4.2.1 Implemented Features

- Route Cache Maintenance
- Send Buffer Maintenance
- Route Request Table Processing
- Maintenance Buffer Processing
- Processing of Received DSR Source Route Option
- Processing of Received Route Request Option
- Processing of Received Route Reply Option
- Processing of Received Route Error Option
- Route Request Origination
- Route Reply Origination
- Route Error Origination
- Generation of Route Reply using the Route Cache
- Packet Salvaging

5.4.2.2 Omitted Features

- FIFO strategy for immature packet drop from packet buffer for buffer overflowing.
- Only option implemented is propagating and non-propagating broadcast of RREQ. Expanding ring search can be implemented.
- Optimization for preventing route reply storm
- Gratuitous route reply table
- Blacklist table
- Network layer acknowledgement
- Automatic route shortening.
- Multiple interface support.
- Route cache is implemented as path cache. Link cache is the other option
- Initiating Route discovery to send Reply back to source with Piggybacking the Reply option.

5.4.2.3 Assumptions and Limitations

- Physical link needs bidirectional communication to send unicast packets.
- Route reply will be reversed back to the source.
- Route request will be sent as a separate packet.
- This protocol is only applicable for wireless scenario.
- MAC layer has packet transmission acknowledgement method.

5.4.3 Command Line Configuration

To specify DSR as the routing protocol, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   ROUTING-PROTOCOL         DSR
```

The scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

DSR Parameters

Table 5-19 describes the DSR configuration parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 5-19. DSR Parameters

Parameter	Value	Description
`DSR-BUFFER-MAX-PACKET` Optional *Scope:* All	Integer *Range:* `> 0` *Default:* `50` *Unit:* packets	Specifies the maximum size of the message buffer in packets. **Note:** The maximum buffer size also depends on the parameter `DSR-BUFFER-MAX-BYTE`.
`DSR-BUFFER-MAX-BYTE` Optional *Scope:* All	Integer *Range:* `≥ 0` *Unit:* bytes	Specifies the maximum size of the message buffer in bytes. **Note:** If this parameter is not specified, then the maximum buffer size is `DSR-BUFFER-MAX-PACKET` packets. If `DSR-BUFFER-MAX-BYTE` is specified, then the maximum buffer size is `DSR-BUFFER-MAX-BYTE` bytes, irrespective of the value of `DSR-BUFFER-MAX-PACKET`.
`ROUTING-STATISTICS` Optional *Scope:* Global, Node	List: • `YES` • `NO` *Default:* `NO`	Indicates whether statistics are collected for DSR protocol.

5.4.4 GUI Configuration

This section describes how to configure DSR in the GUI.

Configuring DSR Parameters

To configure the DSR parameters, perform the following steps:

1. Go to one of the following locations:

- To set properties for a specific wireless subnet, go to **Wireless Subnet Properties Editor > Routing Protocol > General**.
- To set properties for a specific node, go to **Default Device Properties Editor > Node Configuration > Routing Protocol**.
- To set properties for a specific interface of a node, go to one of the following locations:
  - **Interface Properties Editor > Interfaces > Interface # > Routing Protocol**.
  - **Default Device Properties Editor > Interfaces > Interface # > Routing Protocol**.

In this section, we show how to configure DSR parameters for a specific node using the Default Device Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **Routing Protocol IPv4** to *DSR* and set the dependent parameters listed in Table 5-20.

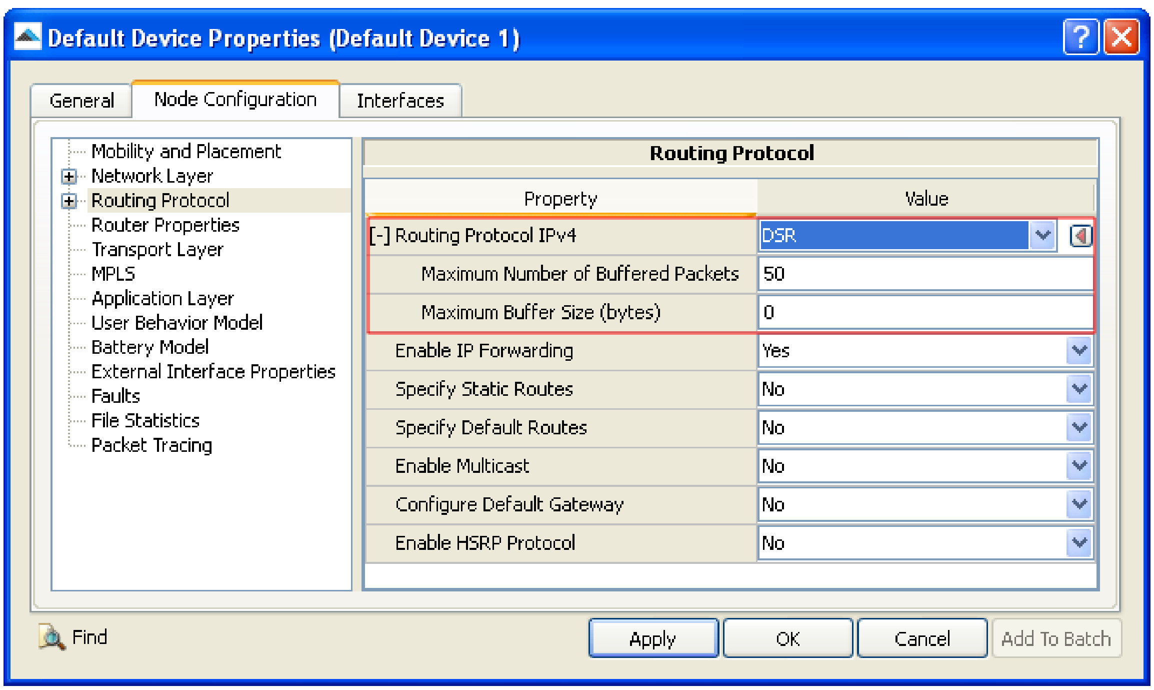


FIGURE 5-12. Setting DSR Parameters

TABLE 5-20. Command Line Equivalent of DSR Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Maximum Number of Buffered Packets	Node, Subnet, Interface	`DSR-BUFFER-MAX-PACKET`
Maximum Buffer Size	Node, Subnet, Interface	`DSR-BUFFER-MAX-BYTE`

Configuring Statistics Parameters

Statistics for DSR can be collected at the global and node levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for routing protocols including DSR, check the box labeled **Routing** in the appropriate properties editor.

TABLE 5-21. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Routing	Global, Node	`ROUTING-STATISTICS`

5.4.5 Statistics

Table 5-22 shows the DSR statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 5-22. DSR Statistics

Statistic	Description
Number of RREQ Initiated	Total number of Route Requests initiated by a node.
Number of RREQ Retried	Total number of Route Requests retransmitted by a node.
Number of RREQ Forwarded	Total number of Route Requests forwarded by a node.
Number of RREQ received	Total number of Route Requests received by a node.
Number of Duplicate RREQ received	Total number of duplicate Route Requests received.
Number of RREQ ttl expired	Total number of Route Requests received by a node which was not relayed because of expiration of TTL.
Number of RREQ received by Dest	Total number of Route Requests received as the target node.
Number of RREQ discarded for loop	Total number of Route Requests discarded for detecting a routing loop.
Number of RREP Initiated as Dest	Total number of Route Replies originated at target node.
Number of RREP Initiated as intermediate node	Total number of cached route reply originated as an intermediate node.
Number of RREP Received	Total number of Route Replies received by a node.
Number of RREP Received as Source	Total number of Route Replies received by the source node.
Number of RERR Initiated	Total number of Route Errors originated by a node.
Number of RERR received as source	Total number of Route Errors received by the source node.
Number of RERR received	Total number of Route Errors received by an intermediate node.
Number of Data packets sent as Source	Total number of data packets sent by a node.
Number of Data Packets Forwarded	Total number of data packets forwarded by a node.
Number of Data Packets Received	Total number of data packets received by a destination node.
Number of Data Packets Dropped for no route	Total number of packets dropped from DSR packet buffer because of no route.
Number of Data Packets Dropped for buffer overflow	Total number of data packets dropped from packet buffer for overflow.
Number of times Retransmission failed	Total number of data packets dropped after Maximum Retransmission.
Number of Routes Selected	Total number of new routes found by a node.

TABLE 5-22. DSR Statistics (Continued)

Statistic	Description
Number of Hop Counts	Accumulated number of hops of all routes found by DSR at a node.
Number of packet salvaged	Total number of packets a node salvaged.
Number of times Mac failed to transmit data	Total number of times MAC layer failed to transmit a data packet.
Number of Packets Dropped for Exceeding MTU	Total number of data packets dropped because it's size exceeds MTU.

5.4.6 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the DSR model. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/dsr. Table 5-23 lists the sub-directory where each scenario is located.

TABLE 5-23. DSR Scenarios Included in EXata

Scenario	Description
cache-reply/rrep-rc-bs1	Shows Cached Route Reply of DSR protocol for 7 nodes in wireless scenario.
cache-reply/rrep-rc-ns1	Shows Cached Route Reply of DSR protocol for 7 nodes in wireless scenario.
maintenance-buffer/ mbp-bs1	Shows Maintenance Buffer of DSR protocol for 8 nodes in wireless scenario.
maintenance-buffer/ mbp-ns1	Shows Maintenance Buffer of DSR protocol for 6 nodes in wireless scenario.
message-buffer/send-buffer	Shows the behavior of Send Buffer for 6 nodes in wireless scenario.
miscellaneous/mt-bs1	Shows the overall behavior of DSR protocol for 11 nodes in wireless scenario.
miscellaneous/mt-bs2	Shows the overall behavior of DSR protocol for 8 nodes in wireless scenario.
miscellaneous/mt-bs3	Shows the overall behavior of DSR protocol for 15 nodes in wireless scenario.
miscellaneous/mt-ns1	Shows the overall behavior of DSR protocol for 15 nodes in wireless scenario.
packet-salvage/salvage	Shows the Packet salvaging of DSR protocol for 6 nodes in wireless scenario.
route-cache/rcm-bs1	Shows the Route Cache Maintenance of DSR protocol for 5 nodes in wireless scenario.
route-error/rerr	Shows the processing of Route Error of DSR protocol for 8 nodes in wireless scenario.

5.4.7 References

1. Draft-ietf-manet-dsr-07, "The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks (DSR)", David B. Johnson, David A. Maltz, Yih-Chun Hu, Jorjeta G.Jetcheva. February 2002.

5.5 Fisheye State Routing Protocol

The EXata Fisheye State Routing Protocol is based on the following documents:

- draft-ietf-manet-fsr-03.
- Scalable Routing Strategies for Ad-hoc Wireless Networks.

5.5.1 Description

Fisheye State Routing (FSR) is a link state type protocol that maintains a topology map at each node. FSR differs from the standard link state algorithm in the following:

- Having only neighboring nodes exchange the link state information.
- Utilizing only time-triggered, not event-triggered link state exchanges.
- Using different exchange intervals for nearby versus far away nodes.

5.5.2 Command Line Configuration

To specify Fisheye State Routing as the routing protocol, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   ROUTING-PROTOCOL        FISHEYE
```

The scope of this parameter declaration can be Global, Node, Subnet or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

Fisheye State Routing Parameters

Table 5-24 shows the Fisheye State Routing configuration parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 5-24. Fisheye State Routing Parameters

Parameter	Value	Description
`FISHEYE-SCOPE` *Optional* *Scope:* All	Integer *Range:* `> 0S` *Default:* `2`	Specifies the scope limitation of local routing.
`FISHEYE-INTRA-UPDATE-INTERVAL` *Optional* *Scope:* All	Time *Range:* `> 0S` *Default:* `2S`	Specifies the routing table update frequency within the Fisheye scope.

TABLE 5-24. Fisheye State Routing Parameters (Continued)

Parameter	Value	Description
FISHEYE-INTER-UPDATE-INTERVAL *Optional* *Scope:* All	Time *Range:* > 0S *Default:* 4S	Specifies the routing table update frequency outside of the Fisheye scope.
FISHEYE-NEIGHBOR-TIMEOUT-INTERVAL *Optional* *Scope:* All	Time *Range:* > 0S *Default*: 6S	Specifies the occurrence of the timeout event for the expiration period of the neighbor list.

5.5.3 GUI Configuration

This section describes how to configure Fisheye State Routing Protocol for an IPv4 node in the GUI. It can be configured in a similar way for a Dual IP node also.

Configuring Fisheye State Routing Protocol Parameters

To configure the Fisheye State Routing Protocol parameters, perform the following steps:

1. Go to one of the following locations:
   - To set properties for a specific wireless subnet, go to **Wireless Subnet Properties Editor > Routing Protocol**.
   - To set properties for a specific wired subnet, go to **Wired Subnet Properties Editor > Routing Protocol**.
   - To set properties for a specific point-to-point link, go to **Point-to-point Link Properties Editor > Point-to-point Link Properties > Routing Protocol**.
   - To set properties for a specific node, go to **Default Device Properties Editor > Node Configuration > Routing Protocol**.
   - To set properties for a specific interface of a node, go to one of the following locations:
     - **Interface Properties Editor > Interfaces > Interface # > Routing Protocol**.
     - **Default Device Properties Editor > Interfaces > Interface # Routing Protocol**.

   In this section, we show how to configure Fisheye State Routing Protocol parameters for a specific node using the Default Device Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **Routing Protocol IPv4** to *Fisheye* and set the dependent parameters listed in Table 5-25.

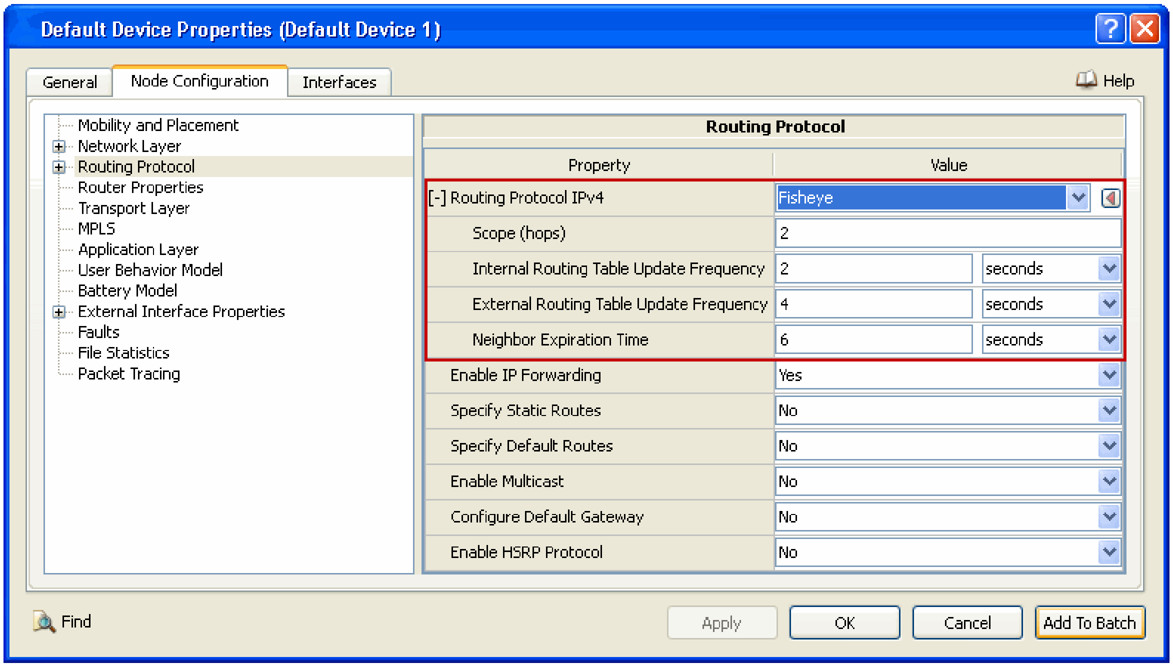


FIGURE 5-13. Setting Fisheye State Routing Protocol Parameters

TABLE 5-25. Command Line Equivalent Fisheye State Routing Protocol Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Scope	Node, Subnet, Interface	FISHEYE-SCOPE
Internal Routing Table Update Frequency	Node, Subnet, Interface	FISHEYE-INTRA-UPDATE-INTERVAL
External Routing Table Update Frequency	Node, Subnet, Interface	FISHEYE-INTER-UPDATE-INTERVAL
Neighbor Expiration Time	Node, Subnet, Interface	FISHEYE-NEIGHBOR-TIMEOUT-INTERVAL

Configuring Statistics Parameters

Statistics for Fisheye State Routing Protocol can be collected at the global and node levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for Fisheye State Routing Protocol, check the box labeled Routing in the appropriate properties editor.

TABLE 5-26. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Routing	Global, Node	ROUTING-STATISTICS

5.5.4 Statistics

Table 5-27 shows Fisheye State Routing statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 5-27. Fisheye State Routing Statistics

Statistic	Description
Number of intra scope updates sent	Total number of inner scope topology updates.
Number of inter scope updates sent	Total number of outer scope topology updates.
Number of control packets received	Total number of control packets received from transport layer.
Control Overhead in Bytes	Total number of control overheads in bytes.

5.5.5 References

1. draft-ietf-manet-fsr-03. "Fisheye State Routing Protocol (FSR) for Ad Hoc Networks." Mario Gerla, Xiaoyan Hong, Guangyu Pei. June 17, 2002.
2. A. Iwata, Ching-Chuan Chiang, Guangyu Pei, M. Gerla, Tsu-Wei Chen. "Scalable Routing Strategies for Ad hoc Wireless Networks". *IEEE journal on selected areas in communications. Volume 17, Issue 8, Aug 1999, 1369, 1379.*

5.6 Intrazone Routing Protocol (IARP)

The EXata IARP model is based on the draft-ietf-manet-zone-iarp-02.

5.6.1 Description

Intrazone Routing protocol (IARP) is a component of the Zone Routing Protocol (ZRP). It is a proactive routing protocol used inside a zone. However, it can also be used as a standalone mode.

5.6.2 Command Line Configuration

To specify IARP as the routing protocol, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   ROUTING-PROTOCOL         IARP
```

The scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

IARP Parameters

Table 5-28 describes the IARP configuration parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 5-28. IARP Parameters

Parameter	Value	Description
`ZONE-RADIUS` *Optional* *Scope:* All	Integer *Range:* ≥ 0 *Default:* 2	Specifies the zone radius.
`ROUTING-STATISTICS` *Optional* *Scope:* Global, Node	List: • `YES` • `NO` *Default:* `NO`	Indicates whether statistics are collected for routing protocols, including IARP.

5.6.3 GUI Configuration

This section describes how to configure IARP in the GUI.

Configuring IARP Parameters

To configure the IARP parameters, perform the following steps:

1. Go to one of the following locations:
   - To set properties for a specific wireless subnet, go to **Wireless Subnet Properties Editor > Routing Protocol > General**.
   - To set properties for a specific node, go to **Default Device Properties Editor > Node Configuration > Routing Protocol**.
   - To set properties for a specific interface of a node, go to one of the following locations:
     - **Interface Properties Editor > Interfaces > Interface # > Routing Protocol**.

- **Default Device Properties Editor > Interfaces > Interface # > Routing Protocol**.

In this section, we show how to configure IARP parameters for a specific node using the Default Device Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **Routing Protocol IPv4** to *IARP* and set the dependent parameters listed in Table 5-29.

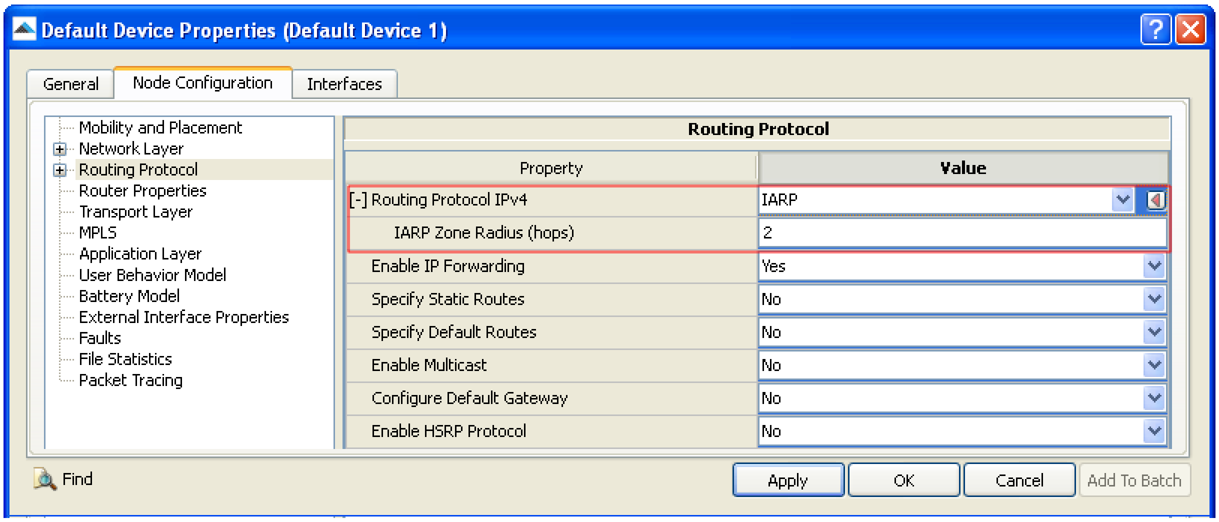


FIGURE 5-14. Setting IARP Parameters

TABLE 5-29. Command Line Equivalent of IARP Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
IARP Zone Radius	Node, Interface, Subnet	`ZONE-RADIUS`

Configuring Statistics Parameters

Statistics for IARP can be collected at the global and node levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for routing protocols including IARP, check the box labeled **Routing** in the appropriate properties editor.

TABLE 5-30. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Routing	Global, Node	`ROUTING-STATISTICS`

5.6.4 Statistics

This section describes the file and dynamic statistics of the IARP model.

5.6.4.1 File Statistics

Table 5-31 shows the IARP statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 5-31. IARP Statistics

Statistic	Description
Number of triggered updates sent	Number of triggered updates sent by the node.
Number of regular updates sent	Number of regular updates sent by the node.
Number of update messages relayed	Number of update messages relayed by the node.
Number of update messages received	Number of update messages received by the node.
Number of packets routed	Number of packets routed by the node.

5.6.4.2 Dynamic Statistics

The following dynamic statistics are enabled for the IARP model (refer to Chapter 6 of *EXata User's Guide* for details of viewing dynamic statistics in the GUI during the simulation):

- Number of Triggered Update Messages Sent
- Number of Regular Update Messages Sent
- Number of Update Messages Relayed
- Number of Update Messages Received
- Number of Packets Routed
- Number of Query Packets Sent
- Number of Query Packets Received
- Number of Query Packets Relayed
- Number of Reply Packets Sent
- Number of Reply Packets Received
- Number of Reply Packets Relayed
- Number of Packets Routed via IERP
- Number of Data Packets Dropped due to Buffer Overflow

5.6.5 References

1. Draft-ietf-manet-zone-iarp-02, "The Intrazone Routing Protocol (IARP) for Ad Hoc Networks", Zygmunt J. Haas, Marc R. Pearlman, Prince Samar. July 2002.

5.7 Interzone Routing Protocol (IERP)

The EXata IERP model is based on the draft-ietf-manet-zone-ierp-02.

5.7.1 Description

Interzone Routing Protocol (IERP) is a component of the Zone Routing Protocol (ZRP). It is used to discover a route to remote nodes outside of the zone of the node. However, it can also be used as a standalone routing protocol. It is an on-demand routing protocol.

5.7.2 Command Line Configuration

To specify IERP as the routing protocol, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   ROUTING-PROTOCOL         IERP
```

The scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

IERP Parameters

Table 5-32 describes the IERP configuration parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 5-32. IERP Parameters

Parameter	Value	Description
`ZONE-RADIUS` *Optional* *Scope:* All	Integer *Default:* `0`	Specifies the zone radius.
`IERP-MAX-MESSAGE-BUFFER-SIZE` *Optional* *Scope:* All	Integer *Range:* ≥ `0` *Default:* `100` *Unit:* packets	Specifies the maximum buffer size.
`IERP-USE-BRP` *Optional* *Scope:* All	List: • `YES` • `NO` *Default:* `NO`	Specify whether BRP is enabled with IERP for finding the route beyond the zone radius.
`ROUTING-STATISTICS` *Optional* *Scope:* Global, Node	List: • `YES` • `NO` *Default:* `NO`	Indicates whether statistics are collected for IERP.

5.7.3 GUI Configuration

This section describes how to configure IERP in the GUI.

Configuring IERP Parameters

To configure the IERP parameters, perform the following steps:

1. Go to one of the following locations:
   - To set properties for a specific wireless subnet, go to **Wireless Subnet Properties Editor > Routing Protocol > General**.
   - To set properties for a specific node, go to **Default Device Properties Editor > Node Configuration > Routing Protocol**.
   - To set properties for a specific interface of a node, go to one of the following locations:
     - **Interface Properties Editor > Interfaces > Interface # > Routing Protocol**.
     - **Default Device Properties Editor > Interfaces > Interface # > Routing Protocol**.

   In this section, we show how to configure IERP parameters for a specific node using the Default Device Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **Routing Protocol IPv4** to *IERP* and set the dependent parameters listed in Table 5-33.

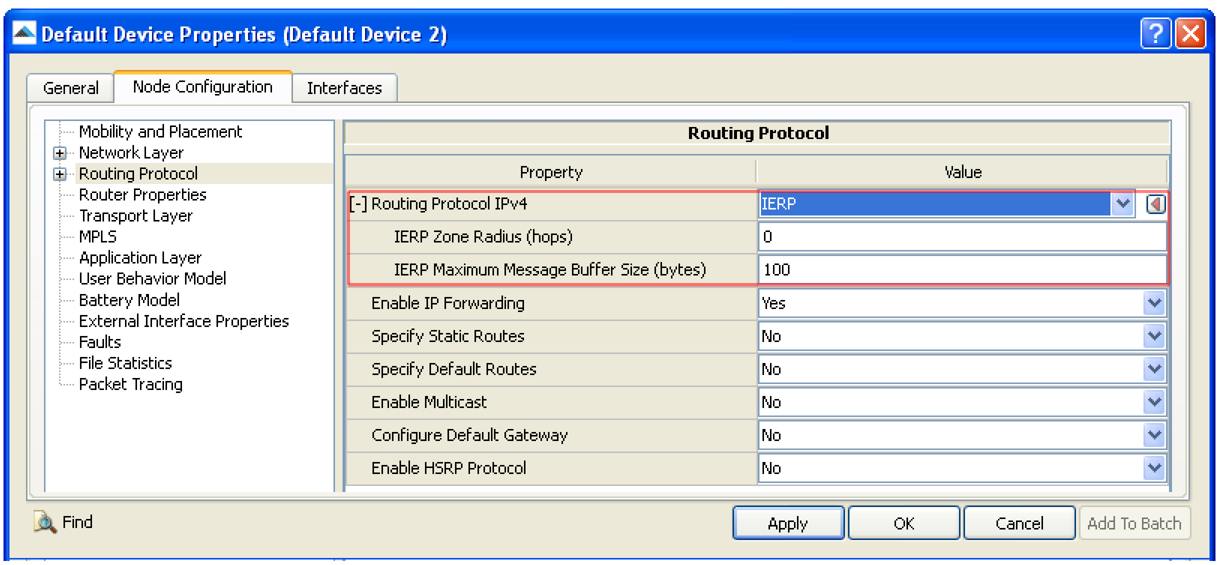


FIGURE 5-15. Setting IERP Parameters

TABLE 5-33. Command Line Equivalent of IERP Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
IERP Zone Radius	Node, Interface, Subnet	`ZONE-RADIUS`
IERP Maximum Message Buffer Size	Node, Interface, Subnet	`IERP-MAX-MESSAGE-BUFFER-SIZE`

Configuring Statistics Parameters

Statistics for IERP can be collected at the global and node levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for routing protocols including IERP, check the box labeled **Routing** in the appropriate properties editor.

TABLE 5-34. Command Line Equivalent of Statistics Parameter

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Routing	Global, Node	`ROUTING-STATISTICS`

5.7.4 Statistics

Table 5-35 shows the IERP statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 5-35. IERP Statistics

Statistic	Description
Number of query packets sent	Number of query packets sent by the node.
Number of query packets received	Number of query packets received by the node.
Number of query packets relayed	Number of query packets relayed by the node.
Number of reply packets sent	Number of reply packets sent by the node.
Number of reply packets received	Number of reply packets received by the node.
Number of reply packets relayed	Number of reply packets relayed by the node.
Number of packets routed via IERP	Number of packets routed via IERP.
Number of data packets dropped because of buffer overflow	Number of data packets dropped because of buffer overflow.

5.7.5 References

1. Draft-ietf-manet-zone-ierp-02, "The Interzone Routing Protocol (IERP) for Ad Hoc Networks", Zygmunt J. Haas, Marc R. Pearlman, Prince Samar. July 2002.

5.8 Landmark Ad Hoc Routing (LANMAR) Protocol

The EXata LANMAR model is based on the draft-ietf-manet-lanmar-04.

5.8.1 Description

Landmark Ad Hoc Routing (LANMAR) protocol utilizes the concept of landmark for scalable routing in large, mobile, ad hoc networks. LANMAR uses Fisheye as the local scope routing protocol.

5.8.2 Features and Assumptions

This section describes the implemented features, omitted features, assumptions and limitations of the LANMAR model.

5.8.2.1 Implemented Features

- Fisheye state routing is used for local scope routing.
- Distance vector routing is used for landmark updates.

5.8.2.2 Omitted Features

None.

5.8.2.3 Assumptions and Limitations

- Nodes are divided into landmark groups as different subnets.
- Nodes in the same landmark group move with similar mobility behavior.
- Group mobility model is configured.

5.8.3 Command Line Configuration

To specify LANMAR as the routing protocol, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   ROUTING-PROTOCOL         FSRL
```

The scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

LANMAR Parameters

Table 5-36 describes the LANMAR configuration parameters. See Section 1.2.1.3 for a description of the format used for the parameter table

TABLE 5-36. LANMAR Parameters

Parameter	Value	Description
`LANMAR-MIN-MEMBER-THRESHOLD` Optional *Scope:* All	Integer *Range:* `> 0` *Default:* `8`	Specifies the minimum number of neighbors in order to be considered a landmark.
`LANMAR-LANDMARK-UPDATE-INTERVAL` *Optional* *Scope:* All	Time *Range:* `> 0` *Default:* `4S`	Specifies the landmark update interval.
`LANMAR-NEIGHBOR-TIMEOUT-INTERVAL` *Optional* *Scope:* All	Time *Range:* `> 0` *Default:* `6S`	Specifies the landmark neighbor timeout interval.
`LANMAR-LANDMARK-MAX-AGE` *Optional* *Scope:* All	Time *Range:* `> 0` *Default:* `12S`	Specifies the maximum age for landmark entries.
`LANMAR-DRIFTER-MAX-AGE` *Optional* *Scope:* All	Time *Range:* `> 0` *Default:* `12S`	Specifies the maximum age for drifter entries.
`LANMAR-FISHEYE-SCOPE` *Optional* *Scope:* All	Integer *Range:* `> 0` *Default:* `2`	Specifies the Fisheye scope for local routing.
`LANMAR-FISHEYE-UPDATE-INTERVAL` *Optional* *Scope:* All	Time *Range:* `> 0` *Default:* `2S`	Specifies the routing table update frequency within the Fisheye scope.
`LANMAR-FISHEYE-MAX-AGE` *Optional* *Scope:* All	Time *Range:* `> 0` *Default:* `6S`	Specifies the maximum age for Fisheye entries.

TABLE 5-36. LANMAR Parameters (Continued)

Parameter	Value	Description
`LANMAR-ALPHA` *Optional* *Scope:* All	Real *Range:* `> 0` *Default:* `1.3`	Specifies the multiplication factor required to update the landmark.
`NETWORK-LAYER-STATISTICS` *Optional* *Scope:* Global, Node	List: • `YES` • `NO` *Default:* `NO`	Indicates whether network layer statistics are collected for LANMAR.

5.8.4 GUI Configuration

This section describes how to configure Landmark Ad Hoc Routing (LANMAR) Protocol for an IPv4 node in the GUI. It can be configured in a similar way for a Dual IP node also.

Configuring Landmark Ad Hoc Routing Protocol Parameters

To configure the LANMAR parameters, perform the following steps:

1. Go to one of the following locations:

- To set properties for a specific wireless subnet, go to **Wireless Subnet Properties Editor > Routing Protocol**.
- To set properties for a specific wired subnet, go to **Wired Subnet Properties Editor > Routing Protocol**.
- To set properties for a specific point-to-point link, go to **Point-to-point Link Properties Editor > Point-to-point Link Properties > Routing Protocol**.
- To set properties for a specific node, go to **Default Device Properties Editor > Node Configuration > Routing Protocol**.
- To set properties for a specific interface of a node, go to one of the following locations:
  - **Interface Properties Editor > Interfaces > Interface # > Routing Protocol**.
  - **Default Device Properties Editor > Interfaces > Interface # Routing Protocol**.

In this section, we show how to configure Landmark Ad Hoc Routing (LANMAR) Protocol parameters for a specific node using the Default Device Properties Editor. Parameters can be set in the other properties editors in a similar way.

1. Set **Routing Protocol IPv4** to *LANMAR* and set the dependent parameters listed in Table 5-37.

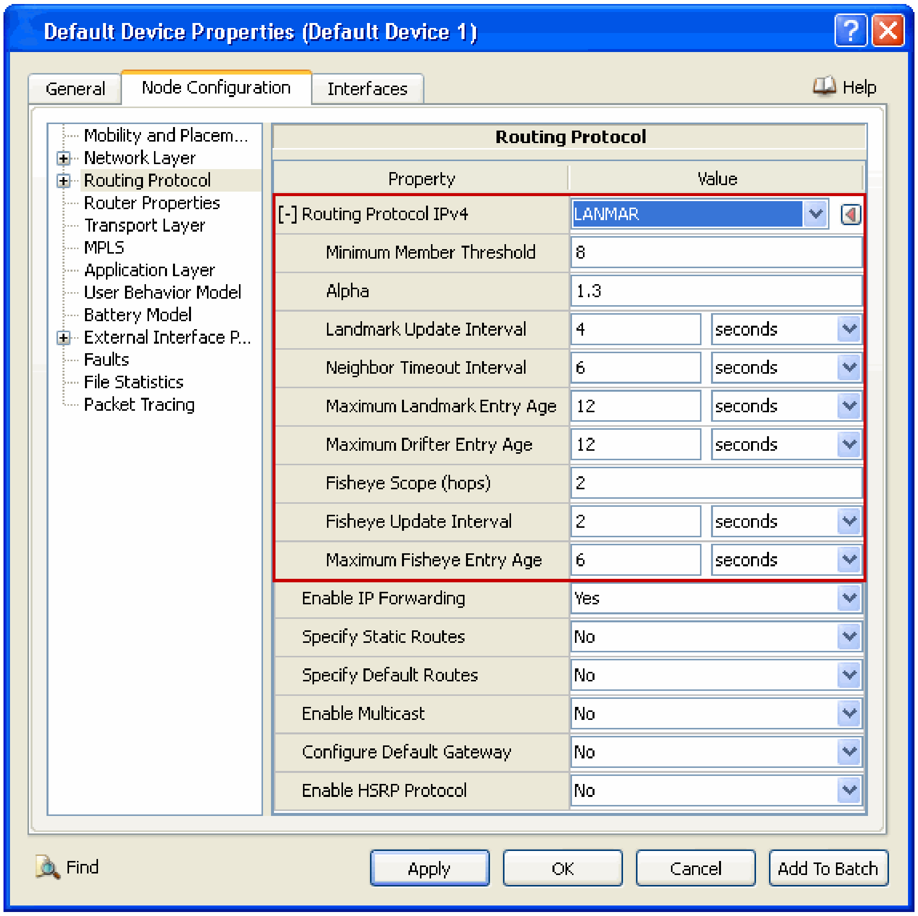


FIGURE 5-16. Setting LANMAR Protocol Parameters

TABLE 5-37. Command Line Equivalent LANMAR Protocol Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Minimum Member Threshold	Node, Subnet, Interface	`LANMAR-MIN-MEMBER-THRESHOLD`
Alpha	Node, Subnet, Interface	`LANMAR-ALPHA`
Landmark Update Interval	Node, Subnet, Interface	`LANMAR-LANDMARK-UPDATE-INTERVAL`
Neighbor Timeout Interval	Node, Subnet, Interface	`LANMAR-NEIGHBOR-TIMEOUT-INTERVAL`
Maximum Landmark Entry Age	Node, Subnet, Interface	`LANMAR-LANDMARK-MAX-AGE`
Maximum Drifter Entry Age	Node, Subnet, Interface	`LANMAR-DRIFTER-MAX-AGE`
Fisheye Scope	Node, Subnet, Interface	`LANMAR-FISHEYE-SCOPE`
Fisheye Update Interval	Node, Subnet, Interface	`LANMAR-FISHEYE-UPDATE-INTERVAL`
Maximum Fisheye Entry Age	Node, Subnet, Interface	`LANMAR-FISHEYE-MAX-AGE`

Configuring Statistics Parameters

Statistics for Landmark Ad Hoc Routing (LANMAR) Protocol can be collected at the global and node levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for Landmark Ad Hoc Routing (LANMAR) Protocol, check the box labeled Routing in the appropriate properties editor.

TABLE 5-38. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Routing	Global, Node	`ROUTING-STATISTICS`

5.8.5 Statistics

Table 5-39 shows the LANMAR statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 5-39. LANMAR Statistics

Statistic	Description
The number of intra-scope updates	Total number of intra update packets sent.
The number of landmark updates	Total number of landmark update packets sent.
Control overhead in bytes	Total number of bytes sent in control packets.
Number of control packets	Total number of control packets sent.
Packets dropped within the scope	Number of data packets dropped where the destination is in the same landmark group, but no route found in intra routing table.
Packets dropped due to no landmark matching	Number of data packets dropped where the destination address has no matching landmark.
Packets dropped due to no drifter matching	Number of data packets dropped where the destination is recognized as a drifter node, but distance is unreachable.
Packets dropped due to no route	Number of data packets dropped where no route can be found to the destination.

5.8.6 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the LANMAR model. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/lanmar. Table 5-40 lists the sub-directory where each scenario is located.

TABLE 5-40. LANMAR Scenarios Included in EXata

Scenario	Description
lanmar-basic	Shows the proper protocol functioning and configuration.
lanmar-control-packets	Shows the proper sending of control packets by each node in a typical setup with sufficient inter-group separation and no mobility.
lanmar-dot11-multichannel	Shows the proper functioning of LANMAR(FSRL) & Dot11 (MAC 802.11) protocol when operates in Multichannel and IBSS mode.
lanmar-dynamic-landmark-election	Shows the proper election of landmark when the current landmark goes down.
lanmar-multiple-interface	Shows that data packets are properly routed to the destination within its own group.

5.8.7 References

1. Draft-ietf-manet-lanmar-04, "The Intrazone Routing Protocol (IARP) for Ad Hoc Networks", Mario Gerla, Xiaoyan Hong, Li Ma. June 2002.

5.9 Location-Aided Routing (LAR) Protocol

5.9.1 Description

Location-Aided Routing (LAR) is an on-demand routing protocol that exploits location information. It is similar to DSR, but with the additional requirement of GPS information.

In scheme 1 (which is implemented here), the source defines a circular area in which the destination may be located and determined by the following information:

- The destination location known to the source
- The time instant when the destination was located at that position
- The average moving speed of the destination.

The smallest rectangular area that includes this circle and the source is the request zone. This information is attached to a ROUTE REQUEST by the source and only nodes inside the request zone propagate the packet. If no ROUTE REPLY is received within the timeout period, the source retransmits a ROUTE REQUEST via pure flooding.

5.9.2 Command Line Configuration

To specify LAR as the routing protocol, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   ROUTING-PROTOCOL         LAR1
```

The scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

LAR Parameters

Table 5-41 describes the LAR configuration parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 5-41. LAR Parameters

Parameter	Value	Description
`ROUTING-STATISTICS` *Optional* *Scope:* Global, Node	List: • `YES` • `NO` *Default:* `NO`	Indicates whether statistics are collected for routing protocols, including LAR.

5.9.3 GUI Configuration

This section describes how to configure LAR in the GUI.

Configuring LAR Parameters

To configure the LAR parameters, perform the following steps:

1. Go to one of the following locations:

- To set properties for a specific wireless subnet, go to **Wireless Subnet Properties Editor > Routing Protocol > General**.
- To set properties for a specific node, go to **Default Device Properties Editor > Node Configuration > Routing Protocol**.
- To set properties for a specific interface of a node, go to one of the following locations:
  - **Interface Properties Editor > Interfaces > Interface # > Routing Protocol**.
  - **Default Device Properties Editor > Interfaces > Interface # > Routing Protocol**.

In this section, we show how to configure LAR parameters for a specific node using the Default Device Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **Routing Protocol IPv4** to *LAR1.*

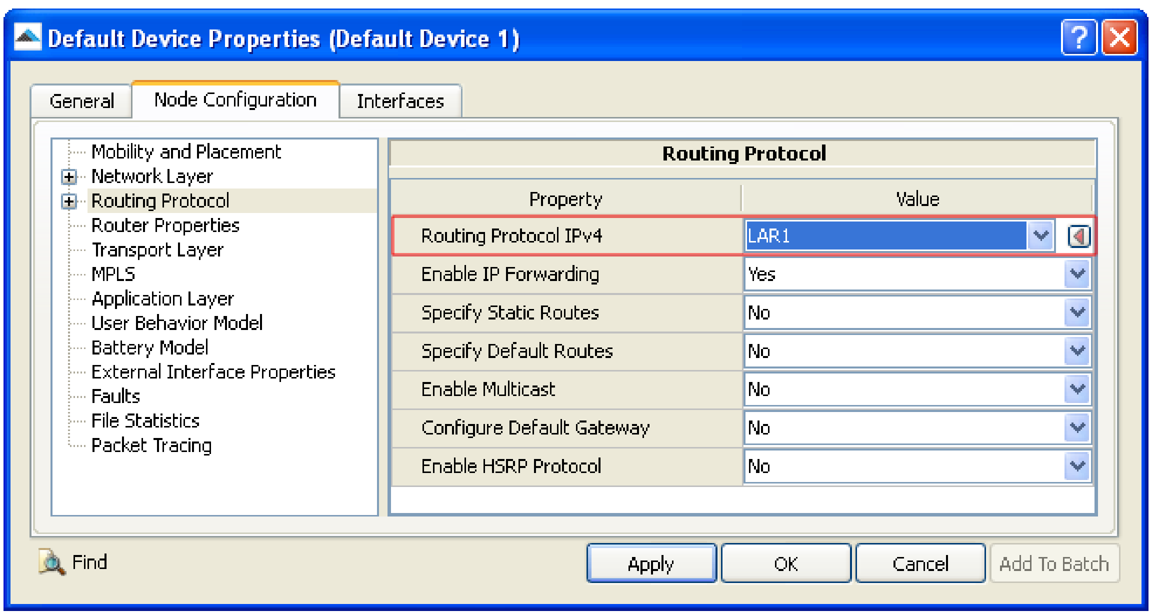


FIGURE 5-17. Setting LAR Parameters

Configuring Statistics Parameters

Statistics for LAR can be collected at the global and node levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for routing protocols including LAR, check the box labeled **Routing** in the appropriate properties editor.

TABLE 5-42. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Routing	Global, Node	`ROUTING-STATISTICS`

5.9.4 Statistics

Table 5-43 shows the LAR statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 5-43. LAR Statistics Collected

Statistic	Description
Data Packets Sent as Data Source	Total number of data packets sent as source of the data by the node.
Data Packets Relayed	Total number of data packets relayed by the node.
Route Requests Sent as Data Source	Total number of route requests sent by a node when it has data to send.
Route Replies Sent as Data Receiver	Total number of route replies sent by a node when it was a destination.
Route Error Packets Sent as Source of Error	Total number of route error packets sent by the node when it was the source of the error.
Route Requests Relayed as Intermediate Node	Total number of route request packets relayed by the node when it was an intermediate hop between the source and the destination.
Route Replies Relayed as Intermediate Node	Total number of route reply packets relayed by the node when it was an intermediate hop between the source and the destination.
Route Error Packets Relayed as Intermediate Node	Total number of route error packets relayed by the node when it was an intermediate hop between the source and the destination.

5.10 Optimized Link State Routing Protocol - INRIA (OLSR-INRIA)

The EXata OLSR-INRIA model is based on RFC 3626.

5.10.1 Description

The Optimized Link State Routing (OLSR) protocol, developed by the French National Institute for Research in Computer Science and Control (INRIA), was developed for mobile ad-hoc networks. It operates in a table-driven and proactive manner, i.e., topology information is exchanged between the nodes on periodic basis. Its main objective is to minimize the control traffic by selecting a small number of nodes, known as Multi Point Relays (MPR) for flooding topological information. In route calculation, these MPR nodes are used to form an optimal route from a given node to any destination in the network. This routing protocol is particularly suited for a large and dense network. OLSR generally proposes four types of periodic control messages, namely:

- Hello messages
- Topology Control (TC) messages
- Multiple Interface Declaration (MID) messages, and
- Host and Network Association (HNA) messages.

Hello messages are periodically exchanged within the one-hop neighborhood to obtain the neighborhood information. Using this neighborhood information, each node in the network selects a subset of one-hop away neighbors known as the MPR set. In the MPR set, all two-hop away neighbors are reachable through any member of the MPR set.

TC messages are generated and retransmitted for flooding topological information in the whole network only through MPR nodes. Also, MID and HNA messages are relayed only by MPR nodes. Therefore, OLSR optimizes the control traffic overhead by minimizing the size of the MPR set. An MPR member generates and retransmits TC messages. These messages provide each node in the network with sufficient link-state information to allow route calculation.

MID messages are generated by an OLSR node with multiple OLSR interfaces to notify other OLSR nodes about its interfaces participating in the OLSR routing domain.

Apart from these OLSR control messages, a node associated with OLSR MANET and non-OLSR MANET periodically issues HNA messages notifying the connected non-OLSR Networks. These HNA messages are also flooded throughout the OLSR domain by the MPR nodes so that the external routes are learned by all the OLSR nodes.

5.10.2 Features and Assumptions

This section describes the implemented features, omitted features, assumptions and limitations of the OLSR-INRIA model.

5.10.2.1 Implemented Features

- OLSR control messages HELLO, TC, MID and HNA.
- Multiple OLSR interfaces support.
- IPv6 interoperability.
- Injection of non OLSR-MANET route into OLSR-MANET domain.
- Forwarding of unsupported OLSR control messages.

- Operability with IPv4-IPv6 networks (DualIP support).

5.10.2.2 Omitted Features

- Link layer notification
- Advanced link sensing
- Redundant topology
- Redundant MPR flooding

5.10.2.3 Assumptions and Limitations

- Every OLSR control packet issued by OLSR contains only one type of control message.
- The interface address with the lowest index participating inside the OLSR-MANET is considered to be the main address for the node.
- A node does not support both IPv4 and IPv6 configurations in an OLSR domain (i.e. a node in dual IP mode), without IP tunneling, i.e., a node can either run OLSR-INRIA in IPv4 mode or IPv6 mode, but not

5.10.3 Command Line Configuration

To select OLSR-INRIA as the routing protocol, include the following parameter(s) in the scenario configuration (.config) file:

- For an IPv4 node, use the following parameter:

```
[<Qualifier>] ROUTING-PROTOCOL          OLSR-INRIA
```

- For an IPv6 node, use *either* of the following parameters:

```
[<Qualifier>] ROUTING-PROTOCOL          OLSR-INRIA
```

or

```
[<Qualifier>] ROUTING-PROTOCOL-IPv6     OLSR-INRIA
```

- For a dual IP-node, use *both* the following parameters:

```
[<Qualifier>] ROUTING-PROTOCOL          OLSR-INRIA
```

and

```
[<Qualifier>] ROUTING-PROTOCOL-IPv6     OLSR-INRIA
```

The scope of these parameter declarations can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

OLSR-INRIA Parameters

Table 5-44 describes the OLSR-INRIA configuration parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 5-44. OLSR-INRIA Parameters

Parameter	Value	Description
OLSR-HELLO-INTERVAL *Optional* *Scope:* All	Time *Range:* > 0S *Default:* 2S	Specifies the time interval between two consecutive HELLO messages within one-hop neighborhood to obtain the neighborhood information.
OLSR-TC-INTERVAL *Optional* *Scope:* All	Time *Range:* > 0S *Default:* 5S	Specifies the time interval between two consecutive TC messages.
OLSR-MID-INTERVAL *Optional* *Scope:* All	Time *Range:* > 0S *Default:* 5S	Specifies the time interval between two consecutive MID messages. MID messages will be broadcasted only when an OLSR node has multiple OLSR interfaces.
OLSR-HNA-INTERVAL *Optional* *Scope:* All	Time *Range:* > 0S *Default:* 5S	Specifies the time interval between two consecutive HNA messages. HNA messages will be broadcasted only when an OLSR node has non-OLSR interface.
OLSR-NEIGHBOR-HOLD-TIME *Optional* *Scope:* All	Time *Range:* > 0S *Default:* 6S	Specifies the occurrence of the timeout event for the validation of tuples in the neighbor tables.
OLSR-TOPOLOGY-HOLD-TIME *Optional* *Scope:* All	Time *Range:* > 0S *Default:* 15S	Specifies the occurrence of the timeout event for the validation of tuples in the topology table.
OLSR-DUPLICATE-HOLD-TIME *Optional* *Scope:* All	Time *Range:* > 0S *Default:* 30S	Specifies the occurrence of the timeout event for the validation of tuples in the duplicate tables. Duplicate table records information about the most recently received messages to avoid duplicate processing of an already received and processed message.
OLSR-MID-HOLD-TIME *Optional* *Scope:* All	Time *Range:* > 0S *Default:* 15S	Specifies the occurrence of the timeout event for the validation of tuples in the MID table. MID table contains information about the multiple OLSR interfaces of a participating OLSR node connected to OLSR MANET domain.
OLSR-HNA-HOLD-TIME *Optional* *Scope:* All	Time *Range:* > 0S *Default:* 15S	Specifies the occurrence of the timeout event for the validation of tuples in the HNA table. HNA table stores information about gateways inside OLSR domain to get to the associated non-OLSR MANET domain.

TABLE 5-44. OLSR-INRIA Parameters (Continued)

Parameter	Value	Description
`ROUTING-STATISTICS` *Optional* *Scope:* Global, Node	List: • `YES` • `NO` *Default:* `NO`	Indicates whether routing protocol statistics are collected.
`TRACE-OLSR` *Optional* *Scope:* Global, Node	List: • `YES` • `NO` *Default:* `YES`	Indicates whether packet tracing is enabled for OLSR. **Note:** To enable packet tracing, some other parameters need to be configured as well. Refer to Section 4.2.10 of *EXata User's Guide* for details.

5.10.4 GUI Configuration

This section describes how to configure OLSR-INRIA in the GUI.

Configuring OLSR-INRIA

To configure the general OLSR-INRIA parameters, perform the following steps:

1. Go to one of the following locations:

- To set properties for a specific wireless subnet, go to **Wireless Subnet Properties Editor > Routing Protocol > General**.
- To set properties for a specific wired subnet, go to **Wired Subnet Properties Editor > Routing Protocol > General**.
- To set properties at the node level, go to **Default Device Properties Editor > Node Configuration > Routing Protocol**.
- To set properties at the interface level, go to one of the following locations:
  - **Interface Properties Editor > Interfaces > Interface # > Routing Protocol**.
  - **Default Device Properties Editor > Interfaces > Interface # > Routing Protocol**.

In this section, we show how to configure the general OLSR-INRIA parameters in the Wireless Subnet Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **Routing Protocol IPv4** to *OLSR INRIA* and set the dependent parameters listed in Table 5-45.

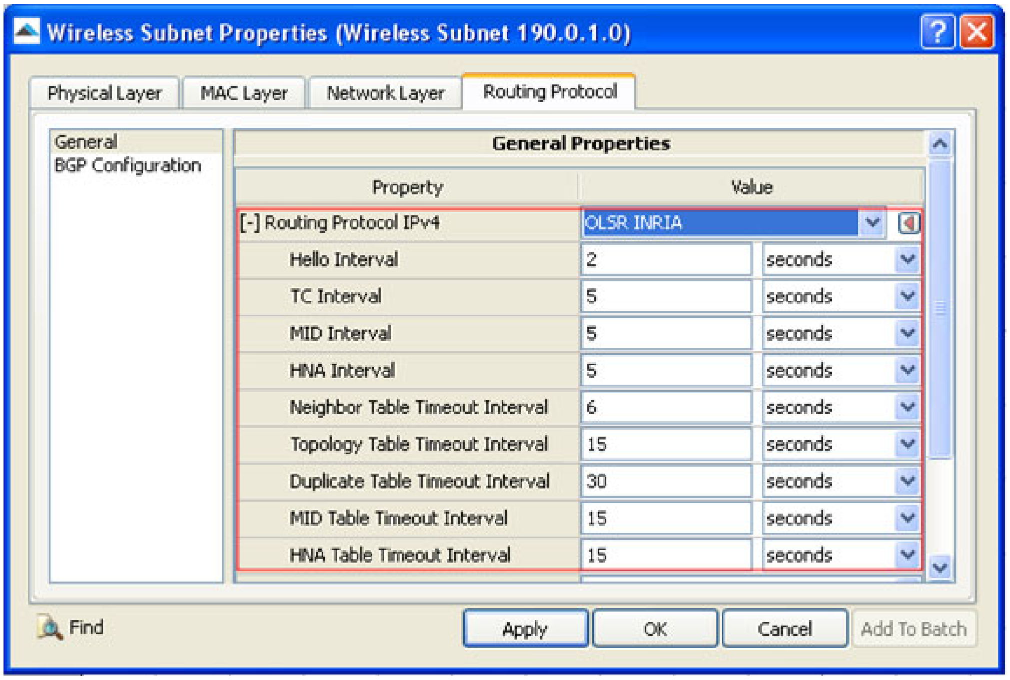


FIGURE 5-18. Setting OLSR-INRIA Parameters

TABLE 5-45. Command Line Equivalent of OLSR-INRIA Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Hello Interval	Subnet, Node, Interface	`OLSR-HELLO-INTERVAL`
TC Interval	Subnet, Node, Interface	`OLSR-TC-INTERVAL`
MID Interval	Subnet, Node, Interface	`OLSR-MID-INTERVAL`
HNA Interval	Subnet, Node, Interface	`OLSR-HNA-INTERVAL`
Neighbor Table Timeout Interval	Subnet, Node, Interface	`OLSR-NEIGHBOR-HOLD-TIME`
Topology Table Timeout Interval	Subnet, Node, Interface	`OLSR-TOPOLOGY-HOLD-TIME`
Duplicate Table Timeout Interval	Subnet, Node, Interface	`OLSR-DUPLICATE-HOLD-TIME`
MID Table Timeout Interval	Subnet, Node, Interface	`OLSR-MID-HOLD-TIME`
HNA Table Timeout Interval	Subnet, Node, Interface	`OLSR-HNA-HOLD-TIME`

Configuring Statistics Parameters

Statistics for OLSR-INRIA can be collected at the global and node levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for Routing protocols including OLSR-INRIA, check the box labeled **Routing** in the appropriate properties editor.

TABLE 5-46. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Routing	Global, Node	`ROUTING-STATISTICS`

Configuring Packet Tracing Parameters

Packet tracing for OLSR-INRIA can be enabled at the global and node levels. To enable packet tracing for OLSR-INRIA, in addition to setting the OLSR-INRIA trace parameter, **Trace OLSR**, several other trace parameters also need to be set. See Section 4.2.10 of *EXata User's Guide* for details of configuring packet tracing parameters.

TABLE 5-47. Command Line Equivalent of Packet Tracing Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Trace OLSR	Global, Node	`TRACE-OLSR`

5.10.5 Statistics

Table 5-48 shows the OLSR-INRIA statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 5-48. OLSR-INRIA Statistics

Statistic	Description
Hello Messages Received	Total number of Hello Messages Received by the node
Hello Messages Sent	Total number of Hello Messages Sent by the node
TC Messages Received	Total number of TC Messages Received by the node
TC Messages Generated	Total number of TC Messages Generated by the node
TC Messages Relayed	Total number of TC Messages Relayed by the node
MID Messages Received	Total number of MID Messages Received by the node
MID Messages Generated	Total number of MID Messages Generated by the node
MID Messages Relayed	Total number of MID Messages Relayed by the node
HNA Messages Received	Total number of HNA Messages Received by the node
HNA Messages Generated	Total number of HNA Messages Generated by the node
HNA Messages Relayed	Total number of HNA Messages Relayed by the node

5.10.6 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the OLSR-INRIA model. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/olsr-inria. Table 5-49 lists the sub-directory where each scenario is located.

TABLE 5-49. OLSR-INRIA Scenarios Included in EXata

Scenario	Description
ipv4/hna	Shows the functionality of HNA implementation in an IPv4 scenario for computation of routes to NON-OLSR domain.
ipv4/mid	Shows the functionality of MID implementation for the computation of MID Table in an IPv4 scenario.
ipv4/mpr-selection	Shows the selection of MPR and generation of TC messages in an IPv4 scenario.
ipv4/mpr-selector	Shows that the proper MPR selector table is being maintained by the nodes in an IPv4 scenario.
ipv6/hna	Shows the functionality of HNA implementation in an IPv6 scenario for the computation of routes to NON-OLSR domain.
ipv6/mid	Shows the functionality of MID implementation for the computation of MID Table in an IPv6 scenario.
ipv6/mpr-selection	Shows the selection of MPR and generation of TC messages in an IPv6 scenario.
ipv6/mpr-selector	Shows that proper MPR selector table is being maintained by the nodes in an IPv6 scenario.
ipv4-ipv6/v4bford-v6o-v4bford	Shows the OLSR implementation for v4-v6-v4 type tunneling with Bellmanford on ipv4 networks and OLSR running on ipv6 network.
ipv4-ipv6/v4o-v6ripng-v4o	Shows the OLSR implementation for v4-v6-v4 type tunneling with OLSR on ipv4 networks and RIPng running on ipv6 network.
ipv4-ipv6/v6o-v4rip-v6o	Shows the OLSR implementation for v6-v4-v6 type tunneling OLSR on ipv6 networks and RIP running on ipv4 network.
ipv4-ipv6/v6ripng-v4o-v6ripng	Shows the OLSR implementation for v6-v4-v6 type tunneling RIPng on ipv6 networks and OLSR running on ipv4 network.

5.10.7 References

1. RFC 3626, "Optimized Link State Routing Protocol (OLSR)." T. Clausen, P. Jacquet. October 2003.

5.11 Optimized Link State Routing Protocol version 2 (OLSRv2)

The EXata OLSRv2 model is based on draft-ietf-manet-olsrv2-02.

5.11.1 Description

Optimized Link State Routing Protocol version 2 (OLSRv2) is an update to OLSRv1 as published in RFC3626. Compared to RFC3626, OLSRv2 retains the same basic mechanisms and algorithms, while providing an even more flexible signaling framework and some simplification of the messages being exchanged. Also, OLSRv2 accommodates both IPv4 and IPv6 addresses in a compact fashion.

OLSRv2 is developed for mobile ad hoc networks. It operates as a table driven, proactive protocol, i.e. it exchanges topology information with other nodes of the network regularly. Each node selects a set of its neighbor nodes as "Multi Point Relays" (MPRs). Only nodes that are selected as such MPRs are then responsible for forwarding control traffic intended for diffusion into the entire network. MPRs provide an efficient mechanism for flooding control traffic by reducing the number of transmissions required.

Nodes selected as MPRs also have a special responsibility when declaring link state information in the network. Indeed, the only requirement for OLSRv2 to provide shortest path routes to all destinations is that MPR nodes declare link-state information for their MPR selectors. Additional available link-state information may be utilized for redundancy. Nodes that have been selected as multipoint relays by some neighbor node(s) announce this information periodically in their control messages. Thereby a node announces to the network that it has reachability to the nodes which have selected it as an MPR. Thus, as well as being used to facilitate efficient flooding, MPRs are also used for route calculation from any given node to any destination in the network.

A node selects MPRs from among its one hop neighbors with "symmetric", i.e., bi-directional linkages. Therefore, selecting routes through MPRs automatically avoids the problems associated with data packet transfer over uni-directional links (such as the problem of not getting link-layer acknowledgments for data packets at each hop, for link-layers employing this technique for unicast traffic, and so on).

OLSRv2 is developed to work independently from other protocols. Likewise, OLSRv2 makes no assumptions about the underlying link-layer. However, OLSRv2 may use link-layer information and notifications as and when available and applicable.

It mainly uses two basic types of control packets as stated below:

- Hello Messages: HELLO messages in OLSRv2 serve to:
  - discover links to adjacent OLSR nodes
  - perform bidirectional check on the discovered links
  - advertise neighbors and hence discover 2-hop neighbors
  - single MPR selection
  - advertise own interfaces which participate in MANET

  HELLO messages are emitted periodically, thereby allowing nodes to continuously track changes in their local neighborhoods.

  OLSRv2 applies Neighborhood discovery protocol for HELLO messages to continuously update information repositories describing the node's 1-hop and 2-hop neighbors. Neighborhood discovery protocol using HELLO messages uses generic multi-message packet format, for carrying MANET routing protocol signals.
- TC messages (Topology Control messages) in OLSRv2 serve to:
  - inject link-state information into the entire network

- inject addresses of hosts and networks for which they may serve as a gateway to the entire network
- allow nodes with multiple interface addresses to ensure that nodes within two hops can associate these addresses with a single node for efficient MPR Set determination

TC messages are emitted periodically, thereby allowing nodes to continuously track global changes in the network. A TC message *must* contain:

- a message TLV VALIDITY_TIME
- a message TLV CONTENT_SEQUENCE_NUMBER
- one or more address blocks with associated address block TLVs.

The first (mandatory) address block is a Local Interface Block. Other (optional) address blocks contain 1-hop neighbor’s interface addresses and/or host or network addresses for which this node may act as a gateway. In the latter case they may use PREFIX_LENGTH TLV(s) and must attach GATEWAY TLV(s).

The purpose of OLSRv2 is to determine the Routing Set, which may be used to update IP's Routing Table, and providing "next hop" routing information for IP datagrams. In order to accomplish this, OLSRv2 uses a number of protocol sets:

- Neighborhood Information Base: The neighborhood information base stores information about links between local interfaces and interfaces on adjacent nodes.
- Topology Information Base: The topology information base stores information required for the generation and processing of TC messages.

5.11.2 Features and Assumptions

This section describes the implemented features, omitted features, assumptions and limitations of the OLSRv2 model

5.11.2.1 Implemented Features

- Support for both IPv4 and IPv6 networks.
- IP address compression.
- Attached network address declaration.
- Hop by hop validity time TLV.
- Multiple message aggregation.
- One address compression.
- Link layer notification for IPv4.
- Multiple OLSRv2 interfaces support.

5.11.2.2 Omitted Features

- Multiple address assignment on one interface.
- Link layer notification for IPv6.
- Additional Hello message with Link layer notification.

5.11.3 Command Line Configuration

To select OLSRv2 as the routing protocol, include the following parameter(s) in the scenario configuration (.config) file:

- For an IPv4 node, use the following parameter:

```
[<Qualifier>] ROUTING-PROTOCOL          OLSRv2-NIIGATA
```

- For an IPv6 node, use *either* of the following parameters:

```
[<Qualifier>] ROUTING-PROTOCOL          OLSRv2-NIIGATA
```

or

```
[<Qualifier>] ROUTING-PROTOCOL-IPv6     OLSRv2-NIIGATA
```

- For a dual IP-node, use *both* the following parameters:

```
[<Qualifier>] ROUTING-PROTOCOL          OLSRv2-NIIGATA
```

and

```
[<Qualifier>] ROUTING-PROTOCOL-IPv6     OLSRv2-NIIGATA
```

The scope of these parameter declarations can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

OLSRv2-NIIGATA Parameters

Table 5-50 describes the OLSRv2 configuration parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 5-50. OLSRv2-NIIGATA Parameters

Parameter	Value	Description
OLSRv2-HELLO-INTERVAL *Optional* *Scope:* All	Time *Range:* > 0S *Default:* 2S	Specifies the time interval between two consecutive HELLO messages within one-hop neighborhood to obtain the neighborhood information.
OLSRv2-TC-INTERVAL *Optional* *Scope:* All	Time *Range:* > 0S *Default:* 5S	Specifies the time interval between two consecutive TC messages by the same node.
OLSRv2-REFRESH-TIMEOUT-INTERVAL *Optional* *Scope:* All	Time *Range:* > 0S *Default:* 2S	Specifies the time interval on the occurrences of which the validation of timeout tuples in various repositories are checked with respect to their configured Hold times.
OLSRv2-START-HELLO *Optional* *Scope:* All	Time *Range:* > 0S *Default:* 1S	Specifies the start time of HELLO packet periodic emission by the nodes.

TABLE 5-50. OLSRv2-NIIGATA Parameters (Continued)

Parameter	Value	Description
`OLSRv2-START-TC` *Optional* *Scope:* All	Time *Range:* `> 0S` *Default:* `1S`	Specifies the start time of TC packet periodic emission by the nodes.
`OLSRv2-START-REFRESH-TIMEOUT` *Optional* *Scope:* All	Time *Range:* `> 0S` *Default:* `1S`	Specifies the start time of the periodic timer `OLSRv2-REFRESH-TIMEOUT-INTERVAL` event for the OLSRv2 information repositories.
`OLSRv2-NEIGHBOR-HOLD-TIME` *Optional* *Scope:* All	Time *Range:* `> 0S` *Default:* `6S`	Specifies the expiration time for the validation of timeout tuples in Link set and Symmetric Neighbor set tables.
`OLSRv2-TOPOLOGY-HOLD-TIME` *Optional* *Scope:* All	Time *Range:* `> 0S` *Default:* `15S`	Specifies the expiration time for the validation of timeout tuples in Topology set table.
`OLSRv2-DUPLICATE-HOLD-TIME` *Optional* *Scope:* All	Time *Range:* `> 0S` *Default:* `30S`	Specifies the expiration time for the validation of timeout tuples in ASSN History set, Attached Network set, Forwarded Message set, Processed Message set and Received Message set tables.
`OLSRv2-LINK-LAYER-NOTIFICATION` *Optional* *Scope:* All	List: • `YES` • `NO` *Default:* `NO`	Specifies the settings for the notification of link disconnection from MAC layer. **Note:** This feature is supported for IPv4 only.
`OLSRv2-PACKET-RESTORATION` *Optional* *Scope:* All	List: • `YES` • `NO` *Default:* `YES`	Specifies the packet restoration feature on the event of Link Layer Notification occurred because of any link disconnection. Currently, simple restoration is supported. If this parameter is set to `YES` then it tries to restore the last received packet.
`OLSRv2-RESTORATION-TYPE` *Optional* *Scope:* All	Integer *Range:* `1` *Default:* `1`	Specifies the type of restoration. This can only be set to `1`, which indicates simple restoration.
`OLSRv2-ATTACHED-NETWORK` *Optional* *Scope:* All	String (see note)	Specifies the non-OLSRv2 attached network information to the node that is acting as a gateway.

Note: The value of the parameter `OLSRv2-ATTACHED-NETWORK` is a string which has the following format:

```
<IP-address-1> <length-1>... <IP-address-n> <length-n>
```

where

`<IP-address-`*i*`>`	IP address of the i^{th} attached network
`<length-`*i*`>`	Network prefix length of the i^{th} attached network

Examples of Parameter Usage

The following are examples of the parameter `OLSRv2-ATTACHED-NETWORK`.

1. If the attached network is an IPV4 network with the address as N8-192.0.1.0, then the parameter should be configured as:

   ```
   OLSRv2-ATTACHED-NETWORK   192.0.1.0   24
   ```

   The network prefix length is 24 (32-8).

2. If the OLSRv2 network is attached to two non-OLSRv2 IPv4 networks with addresses N8-192.0.2.0 and N8-192.0.3.0, then the parameter should be configured as:

   ```
   OLSRv2-ATTACHED-NETWORK  192.0.2.0 24 192.0.3.0 24
   ```

3. If the attached network is an IPv6 network with the address N64-2000:0:0:2:0:0:0:0, then the parameter should be configured as:

   ```
   OLSRv2-ATTACHED-NETWORK   2000:0:0:2:0:0:0:0   64
   ```

   In this case, the network prefix length is 64.

4. If the attached network is an IPv6 network with the address N32-2000:0:2:0:0:0:0:0, then the parameter should be configured as:

   ```
   OLSRv2-ATTACHED-NETWORK   2000:0:2:0:0:0:0:0   32
   ```

   In this case, the network prefix length is 32.

5. If the OLSRv2 network is attached to two non-OLSRv2 IPv6 networks with addresses N64-2000:0:0:2:0:0:0:0 and N64-2000:0:0:3:0:0:0:0, then the parameter should be configured as:

   ```
   OLSRv2-ATTACHED-NETWORK  2000:0:0:2:0:0:0:0 64 2000:0:0:3:0:0:0:0 64
   ```

5.11.4 GUI Configuration

This section describes how to configure OLSRv2-NIIGATA in the EXata GUI.

General Configuration

To configure the general OLSRv2-NIIGATA parameters, perform the following steps:

1. Go to one of the following locations:

- To set properties at the wireless subnet level, go to **Wireless Subnet Properties Editor > Routing Protocol > General**.
- To set properties at the wired subnet level, go to **Wired Subnet Properties Editor > Routing Protocol > General**.
- To set properties at the node level, go to **Default Device Properties Editor > Node Configuration > Routing Protocol**.
- To set properties at the interface level, go to one of the following locations:
  - **Interface Properties Editor > Interfaces > Interface # > Routing Protocol**.
  - **Default Device Properties Editor > Interfaces > Interface # > Routing Protocol**.

In this section, we show how to configure the general OLSRv2-NIIGATA parameters in the Wireless Subnet Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **Routing Protocol IPv4** to *OLSRv2 NIIGATA* and set the dependent parameters listed in Table 5-51.

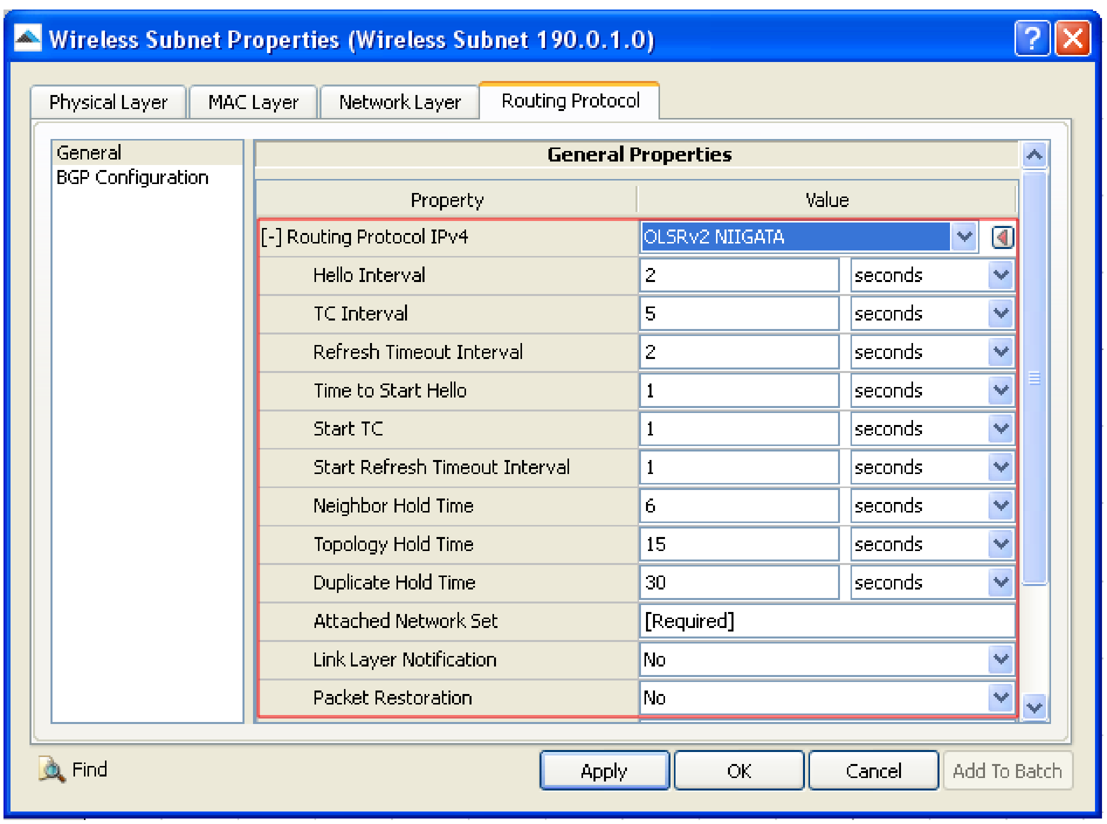


FIGURE 5-19. Setting OLSRv2-NIIGATA Parameters

TABLE 5-51. Command Line Equivalent of OLSRv2-NIIGATA Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Hello Interval	Subnet, Node, Interface	`OLSRv2-HELLO-INTERVAL`
TC Interval	Subnet, Node, Interface	`OLSRv2-TC-INTERVAL`
Refresh Timeout Interval	Subnet, Node, Interface	`OLSRv2-REFRESH-TIMEOUT-INTERVAL`
Time to Start Hello	Subnet, Node, Interface	`OLSRv2-START-HELLO`
Start Refresh Timeout Interval	Subnet, Node, Interface	`OLSRv2-START-REFRESH-TIMEOUT`
Neighbor Hold Time	Subnet, Node, Interface	`OLSRv2-NEIGHBOR-HOLD-TIME`
Topology Hold Time	Subnet, Node, Interface	`OLSRv2-TOPOLOGY-HOLD-TIME`
Attached Network Set	Subnet, Node, Interface	`OLSRv2-ATTACHED-NETWORK`
Link Layer Notification	Subnet, Node, Interface	`OLSRv2-LINK-LAYER-NOTIFICATION`
Packet Restoration	Subnet, Node, Interface	`OLSRv2-PACKET-RESTORATION`
Packet Restoration Type	Subnet, Node, Interface	`OLSRv2-RESTORATION-TYPE`

Configuring Statistics Parameters

Statistics for OLSRv2-NIIGATA can be collected at the global and node levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for Routing protocols including OLSRv2-NIIGATA, check the box labeled **Routing** in the appropriate properties editor.

TABLE 5-52. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Routing	Global, Node	`ROUTING-STATISTICS`

5.11.5 Statistics

Table 5-53 shows the OLSRv2 statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 5-53. OLSRv2 Statistics

Statistic	Description
Hello Messages Received	Total number of Hello messages received by the node.
Hello Messages Sent	Total number of Hello messages sent by the node.
TC Messages Received	Total number of TC messages received by the node.
TC Messages Generated	Total number of TC messages generated by the node.
TC Messages Relayed	Total number of TC messages relayed by the node.
Total Messages Received	Total number of control messages received by the node.
Total Messages Sent	Total number of control messages sent by the node.

TABLE 5-53. OLSRv2 Statistics (Continued)

Statistic	Description
Total Bytes of Messages Received	Total number of bytes of control messages received by the node.
Total Bytes of Messages Sent	Total number of bytes of control messages sent by the node.

5.11.6 Sample Scenario

5.11.6.1 Scenario Description

The sample scenario shows the working of OLSRv2 routing protocol. The scenario contains three nodes, 1 to 3 in Ad-hoc mode. OLSRv2-NIIGATA routing protocol is configured in this scenario. One CBR application is configured from node 1 to node 3. Node 1 sends 500 packets to node 3.

Topology

Figure 5-20 shows the sample scenario topology.

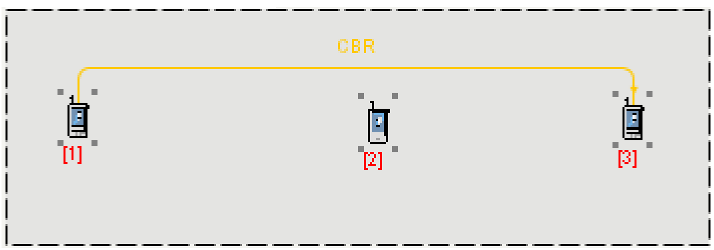


FIGURE 5-20. Sample Scenario Topology: OLSRv2 with IPv4

5.11.6.2 Command Line Configuration

This section describes how to configure the sample scenario for command line for IPV4 and IPv6 networks.

Configuration for IPv4 Networks

To configure the sample scenario for the command line, include the following lines in the scenario configuration (.config) file:

```
# The scenario is executed for a simulation time of 5 minutes
SIMULATION-TIME 5M

# 3 nodes are placed in an ad-hoc multi-hop wireless subnet
SUBNET N8-192.0.0.0 { 1 thru 3 }

#At Global level: OLSRv2-NIIGATA is configured as routing protocol as
below:
[ 1 2 3 ] ROUTING-PROTOCOL OLSRv2-NIIGATA

NETWORK-PROTOCOL                    IP
```

All other OLSRv2-NIIGATA configurable parameters that are not configured in the above example scenario use default values.

Configuration for IPv6 Networks

To configure the sample scenario for the command line, include the following lines in the scenario configuration (.config) file:

```
# The scenario is executed for a simulation time of 5 minutes
SIMULATION-TIME 5M

# 3 nodes are placed in an ad-hoc multi-hop wireless subnet
SUBNET SLA-1 { 1 thru 3 }

#At Global level: OLSRv2-NIIGATA as routing protocol is configured as
below:
[ 1 2 3 ] ROUTING-PROTOCOL OLSRv2-NIIGATA

NETWORK-PROTOCOL              IPv6
```

5.11.6.3 GUI Configuration

To configure the sample scenario in the GUI, perform the following steps.

1. Place 3 nodes on the canvas in ad-hoc mode.

- Select all the three nodes, go to **Default Device Properties Editor > Node Configuration > Routing Protocol**. Set **Routing Protocol IPv4** *to OLSRv2 NIIGATA.*

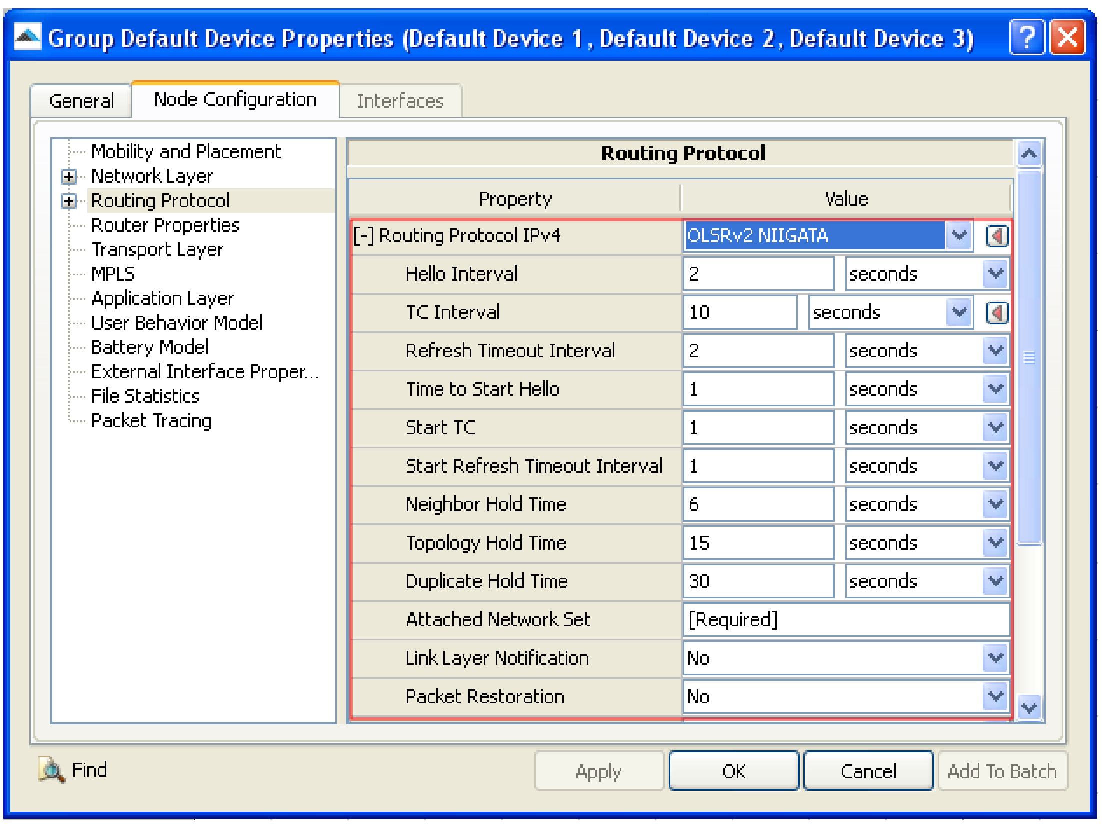


FIGURE 5-21. Setting OLSRv2-NIIGATA as Routing Protocol

2. Select the **Applications** tab of Standard Toolset. Select **CBR** and set the application between Node 1 and Node 3.

5.11.7 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the OLSRv2 model. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/olsrv2-niigata. Table 5-54 lists the sub-directory where each scenario is located.

TABLE 5-54. OLSRv2 Scenarios Included in EXata

Scenario	Description
ipv4/attached-network	Shows the proper learning of the attached networks present with an OLSRv2 network in an IPv4 scenario.
ipv4/hello-test	Shows the proper hello message generation and processing in an IPv4 scenario.
ipv4/mpr-test	Shows the proper selection of MPR and generation of TC messages in an IPv4 scenario.
ipv4/multiple-attached-network	Shows the OLSRv2-NIIGATA functionality for multiple Non-OLSRv2 networks using an IPv4 scenario.
ipv4/multiple-interface	Shows that the proper information is generated for the multiple OLSRv2 interfaces of a node in an IPv4 scenario.
ipv4/tc-test	Shows the proper TC message generation and processing in an IPv4 scenario.
ipv6/attached-network	Shows the proper learning of the attached networks present with an OLSRv2 network in an IPv6 scenario.
ipv6/hello-test	Shows the proper hello message generation and processing in an IPv6 scenario.
ipv6/mpr-test	Shows the proper selection of MPR and generation of TC messages in an IPv6 scenario.
ipv6/multiple-attached-network	Shows the OLSRv2-NIIGATA functionality for multiple Non-OLSRv2 networks using an IPv6 scenario.
ipv6/multiple-interface	Shows that the proper information is generated for the multiple OLSRv2 interfaces of a node in an IPv6 scenario.
ipv6/tc-test	Shows the proper TC message generation and processing in an IPv6 scenario.

5.11.8 References

1. Draft-ietf-manet-olsrv2-02, "The Optimized Link-State Routing Protocol version 2." T. Clausen, C. Dearlove, P. Jacquet. June 2006.
2. Draft-ietf-manet-packetbb-02, "Generalized MANET Packet/Message Format." T. Clausen, C. Dearlove, J. Dean, C. Adjih. July 2006.
3. Draft-ietf-manet-nhdp-01, "MANET Neighborhood Discovery Protocol (NHDP)." T. Clausen, C. Dearlove, J. Dean. February 2007.

5.12 Source Tree Adaptive Routing (STAR) Protocol

The EXata STAR model is based on the paper "Source-Tree Routing in Wireless Networks".

5.12.1 Description

STAR is a partial link state, table driven protocol, in which the routers exchange only the changes in their own shortest path trees with their neighbors. STAR operates in either the Least Overhead Routing Approach (LORA), or Optimum Routing Approach (ORA) modes. In LORA mode, STAR attempts to provide viable, if not necessarily optimal (according to performance and delay metrics) paths to each destination, while in ORA mode, STAR attempts to provide optimal paths based on the chosen metric.

5.12.2 Assumptions and Limitations

- If a node receives a LSU from a neighbor that the Neighbor Protocol has not yet notified STAR about, the node initializes that neighbor in the same way as the Neighbor Protocol does, and then processes the received LSUs. This behavior is equivalent to having the Neighbor Protocol notify STAR just before the reception of the LSUs.
- The assignment of the newly calculated shortest path tree to the source tree is done in ORA mode.

5.12.3 Command Line Configuration

To specify STAR as the routing protocol, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   ROUTING-PROTOCOL        STAR
```

The scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

STAR Parameters

Table 5-55 describes the STAR configuration parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 5-55. STAR Parameters

Parameter	Value	Description
STAR-ROUTING-MODE *Required* *Scope:* All	List: • ORA • LORA	Specifies a choice between the routing modes. With ORA, the routing protocol attempts to update routing tables as quickly as possible to provide paths that are optimum with respect to a defined metric. In contrast, with LORA, the routing protocol attempts to provide viable paths, which need not be optimum, causing the least amount of control traffic.
NEIGHBOR-PROTOCOL-SEND-FREQUENCY *Required* *Scope:* All	Time *Range:* > 0S	Specifies the rate at which the neighbor protocol broadcasts hello packets to all neighbors.
NEIGHBOR-PROTOCOL-ENTRY-TTL *Required* *Scope:* All	Time *Range:* > 0S	Species how long the entries for neighbors remain valid after hearing a hello message.
ROUTING-STATISTICS *Optional* *Scope:* Global, Node	List • YES • NO *Default:* NO	Indicates whether routing protocol statistics are collected.

5.12.4 GUI Configuration

This section describes how to configure STAR in the GUI.

Configuring STAR Parameters

To configure the STAR parameters, perform the following steps:

1. Go to one of the following locations:
   - To set properties for a specific wireless subnet, go to **Wireless Subnet Properties Editor > Routing Protocol > General**.
   - To set properties for a specific node, go to **Default Device Properties Editor > Node Configuration > Routing Protocol**.
   - To set properties for a specific interface of a node, go to one of the following locations:
     - **Interface Properties Editor > Interfaces > Interface # > Routing Protocol**.
     - **Default Device Properties Editor > Interfaces > Interface # > Routing Protocol**.

   In this section, we show how to configure STAR parameters for a specific node using the Default Device Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **Routing Protocol IPv4** to *STAR* and set the dependent parameters listed in Table 5-56.

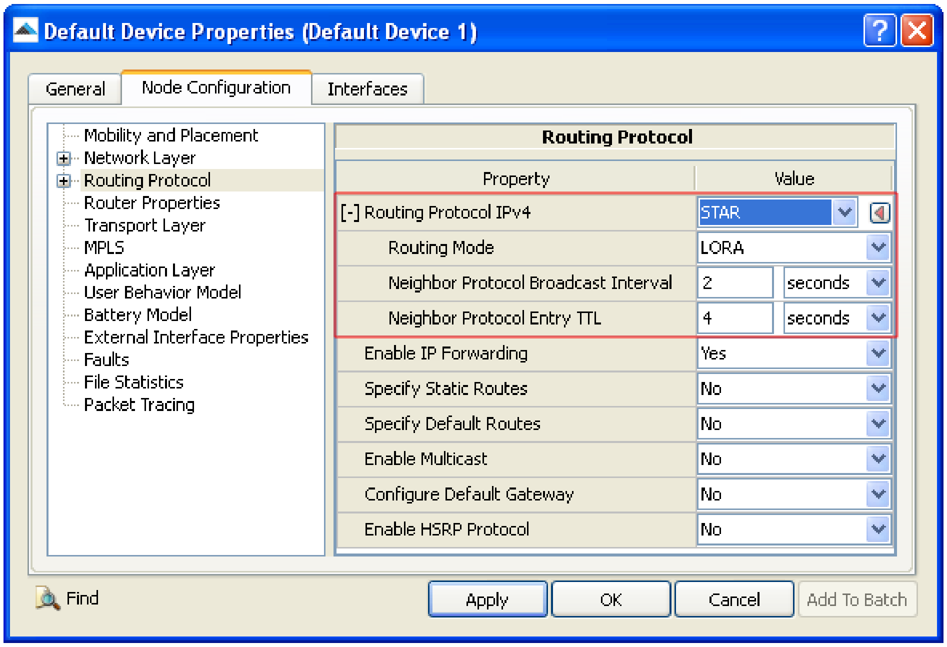


FIGURE 5-22. Setting Routing Protocol to STAR

TABLE 5-56. Command Line Equivalent of STAR Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Routing Mode	Node, Subnet, Interface	`STAR-ROUTING-MODE`
Neighbor Protocol Broadcast Interval	Node, Subnet, Interface	`NEIGHBOR-PROTOCOL-SEND-FREQUENCY`
Neighbor Protocol Entry TTL	Node, Subnet, Interface	`NEIGHBOR-PROTOCOL-ENTRY-TTL`

Configuring Statistics Parameters

Statistics for STAR can be collected at the global and node levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for routing protocols including STAR, check the box labeled **Routing** in the appropriate properties editor.

TABLE 5-57. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Routing	Global, Node	`ROUTING-STATISTICS`

5.12.5 Statistics

Table 5-58 shows the STAR statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 5-58. STAR Statistics

Statistic	Description
Update Packets Sent	Total number of update packets sent by the node.
Update Packets Received	Total number of update packets received by the node.
Link State Updates Sent	Total number of link state updates sent by the node.
Link State Updates Received	Total number of link state updates received by the node.

5.12.6 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the STAR model. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/star. Table 5-59 lists the sub-directory where each scenario is located.

TABLE 5-59. STAR Scenarios Included in EXata

Scenario	Description
Star-Lora-5	Shows normal STAR-LORA for 5 nodes in wireless scenario.
Star-Lora-5M	Shows STAR-LORA for 5 nodes in wireless scenario with mobility.
Star-Ora-3M	Shows STAR-ORA for 3 nodes in wireless scenario with mobility.
Star-Ora-20	Shows normal STAR-ORA for 20 nodes in wireless scenario placed uniformly.

5.12.7 References

1. J.J. Garcia-Luna-Aceves, M. Spohn. "Source-Tree Routing in Wireless Networks." Proceedings of the 7th Annual IEEE international conference on Network Protocols, Toronto, Canada. October 31-November 3, 1999. http://www.ieee-icnp.org/ 1999/ papers/1999-29.pdf.

5.13 Zone Routing Protocol (ZRP)

The EXata ZRP model is based on the draft-ietf-manet-zone-zrp-04.

5.13.1 Description

Zone Routing Protocol (ZRP) is a hybrid protocol that divides the network into overlapping zones and runs independent protocols within and between the zones. For intrazone routing, ZRP uses IARP. For interzone routing, ZRP uses IERP. A third protocol, Bordercast Resolution Protocol (BRP), is used to optimize the routing process between perimeter nodes.

For more information on these models, refer the IARP, IERP and BRP sections of this model library.

5.13.2 Command Line Configuration

To specify ZRP as the routing protocol, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   ROUTING-PROTOCOL         ZRP
```

This scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

ZRP Parameters

Table 5-60 describes the ZRP configuration parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 5-60. ZRP Parameters

Parameter	Value	Description
`ZONE-RADIUS` *Optional* *Scope:* All	Real *Range:* ≥ `0` *Default:* `2` (for IARP) `0` (for IERP)	Specifies the zone radius.
`IERP-USE-BRP` *Optional* *Scope:* All	List: • `YES` • `NO` *Default:* `NO`	Specifies whether BRP is enabled with IERP for finding the route beyond the zone radius.

TABLE 5-60. ZRP Parameters

Parameter	Value	Description
IERP-MAX-MESSAGE-BUFFER-SIZE *Optional* *Scope:* All	Integer *Range:* > 0 *Default:* 100 *Unit:* Bytes	Specifies the maximum buffer size in bytes.
ROUTING-STATISTICS *Optional* *Scope:* Global, Node	List: • YES • NO *Default:* NO	Indicates whether routing protocol statistics are collected.

5.13.3 GUI Configuration

This section describes how to configure ZRP in the EXata GUI.

5.13.3.1 Configuring ZRP Parameters

To configure the ZRP parameters, perform the following steps:

1. Go to one of the following locations:
   - To set properties for a specific wireless subnet, go to **Wireless Subnet Properties Editor > Routing Protocol > General**.
   - To set properties for a specific node, go to **Default Device Properties Editor > Node Configuration > Routing Protocol**.
   - To set properties for a specific interface of a node, go to one of the following locations:
     - **Interface Properties Editor > Interfaces > Interface # > Routing Protocol**.
     - **Default Device Properties Editor > Interfaces > Interface # > Routing Protocol**.

   In this section, we show how to configure ZRP parameters for a specific node using the Default Device Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **Routing Protocol IPv4** to *ZRP* and set the dependent parameters listed in Table 5-61.

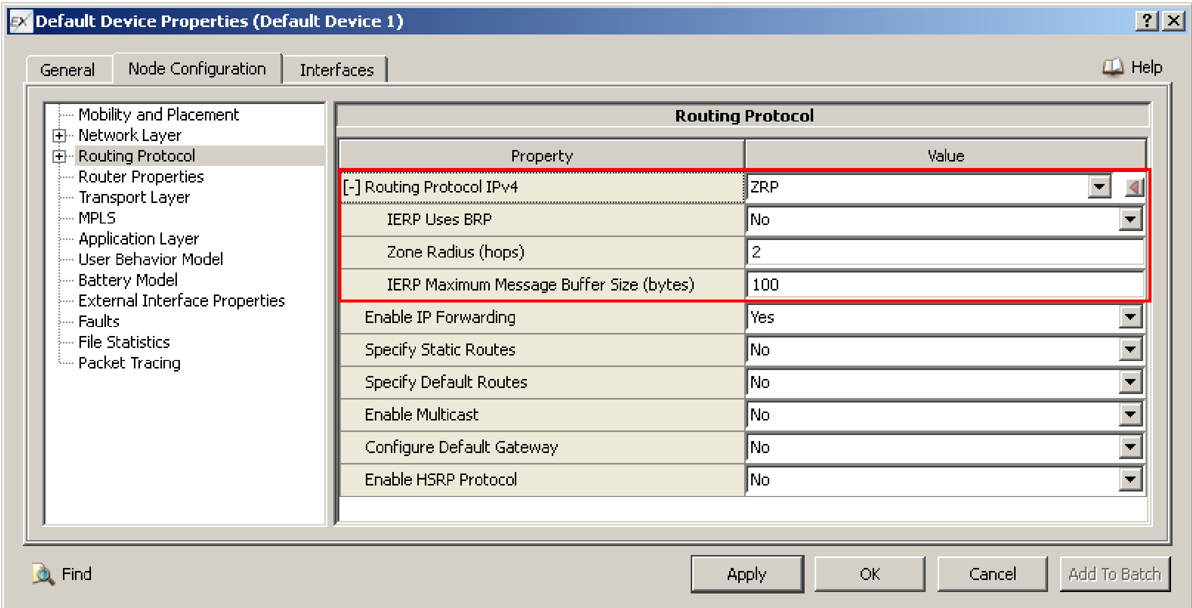


FIGURE 5-23. Setting ZRP Parameters

TABLE 5-61. Command Line Equivalent of ZRP Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
IERP Uses BRP	Node, Subnet, Interface	`IERP-USE-BRP`
Zone Radius	Node, Subnet, Interface	`ZONE-RADIUS`
IERP Maximum Message Buffer Size	Node, Subnet, Interface	`IERP-MAX-MESSAGE-BUFFER-SIZE`

Setting Parameters

- Set **IERP Uses BRP** to *Yes*, if BRP has to be enabled along with IERP to find the route beyond zone radius; otherwise set **IERP Uses BRP** to *No*.
- If IERP is used in the scenario, set **IERP Maximum Message Buffer Size**.

Configuring Statistics Parameters

Statistics for ZRP can be collected at the global and node levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for routing protocols including ZRP, check the box labeled **Routing** in the appropriate properties editor.

TABLE 5-62. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Routing	Global, Node	`ROUTING-STATISTICS`

5.13.4 Statistics

See the BRP, IARP, and IERP sections of this model library for statistics collected by those models.

5.13.5 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the ZRP model. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/zrp. Table 5-63 lists the sub-directory where each scenario is located.

TABLE 5-63. ZRP Scenarios Included in EXata

Scenario	Description
handle-fault	Shows the proper handling of link faults.
iarp-shortest-path	Shows whether IARP finds the shortest path or not.
mobile-ierp	Shows the proper handling of mobile nodes by ZRP.
routing-iarp-ierp	routing-iarp-ierpShows whether the ZRP is sending packets through IERP and IARP simultaneously.
routing-thru-iarp	Shows whether the ZRP is sending packets through IARP.
routing-thru-ierp	Shows whether the ZRP is sending out-of-zone packets through IERP.
routing-thru-ierp-brp/brp-query	Shows whether the node gets the BRP query packets.
routing-thru-ierp-brp/search-own-zone	Shows whether the source node search its own routing zone first.
routing-thru-ierp-brp/zone-radius-increase	Shows whether the node generates IERP query packet along with relaying the query packet and zone radius checking.

5.13.6 References

1. Draft-ietf-manet-zone-zrp-04, "The Zone Routing Protocol (ZRP) for Ad Hoc Networks." Zygmunt J. Haas, Marc R. Pearlman, Prince Samar. July 2002.

6 Multicast Routing Protocol Models

This chapter describes features, configuration requirements and parameters, statistics, and scenarios for Multicast Routing Protocol Models, and consists of the following section:

- On-Demand Multicast Routing Protocol (ODMRP)

6.1 On-Demand Multicast Routing Protocol (ODMRP)

The EXata ODMRP model is based on the following documents:

- draft-yi-manet-pc-00.
- draft-ietf-manet-odmrp-02.
- draft-ietf-manet-odmrp-04.

6.1.1 Description

On-Demand Multicast Routing Protocol (ODMRP) is a wireless multicast routing protocol. It is designed for single subnet, wireless ad-hoc multicast routing, and operates similarly to an on-demand wireless unicast routing protocol. ODMRP is a mesh-based (rather than a conventional tree-based) multicast scheme that uses a forwarding group concept (only a subset of nodes forwards the multicast packets via scoped flooding). It applies on-demand procedures to dynamically build routes and uses soft state to maintain multicast group membership.

6.1.2 Features and Assumptions

This section describes the implemented features, omitted features, assumptions and limitations of the ODMRP model.

6.1.2.1 Implemented Features

The EXata ODMRP model implements the features specified in draft-yi-manet-pc-00, draft-ietf-manet-odmrp-02, and draft-ietf-manet-odmrp-04.

6.1.2.2 Omitted Features

- Mobility prediction using GPS.

6.1.2.3 Assumptions and Limitations

- Acknowledgement packet structure is present.
- Extra 4 bytes are sent with Join Query message.
- Extra two fields are sent with Data Packet attached with IP Options field.
- Join Reply Packet Retransmission is not done in the unicast address.
- If there is a route failure, alternate path finding is postponed until last refresh time.
- Each node has only one interface.
- Due to Passive Clustering, there exists a problem of Critical Path Loss.
- ODMRP-specific information present in Join Query message is not printed in the trace file.

6.1.3 Command Line Configuration

To specify ODMRP as the routing protocol, include the following parameter in the scenario configuration (.config) file:

```
<Qualifier> MULTICAST-PROTOCOL ODMRP
```

The scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

ODMRP Parameters

Table 6-1 describes the ODMRP configuration parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 6-1. ODMRP Parameters

Parameter	Value	Description
`MULTICAST-GROUP-FILE` *Optional* *Scope:* Global	Filename	Name of the Multicast Group file. Refer to *EXata User's Guide* for the description of the Multicast Group file.
`ODMRP-JR-REFRESH` Optional *Scope:* All	Time *Range:* `> 0S` *Default:* `20S`	Specifies the time for periodic Join Query message transmission. With the propagation of Join Query messages, routes are being refreshed, therefore this is also called route refresh. **Note:** For highly mobile nodes, a small route refresh interval should be chosen. For a stable network, larger values provide better network performance.
`ODMRP-FG-TIMEOUT` *Optional* *Scope:* All	Time *Range:* > `ODMRP-JR-REFRESH` *Default:* `60S`	Specifies the Forwarding Group timeout Interval. Once this value expires, a node supporting ODMRP will not forward data packets. **Note:** The value must be 3 to 5 times larger than the route refresh interval.
`ODMRP-DEFAULT-TTL` *Optional* *Scope:* All	Integer *Range:* `(0,255)` *Default:* `64`	Specifies the TTL value for ODMRP routing control packets.
`ODMRP-PASSIVE-CLUSTERING` *Optional* *Scope:* All	List: • `YES` • `NO` *Default:* `NO`	Specifies whether or not to use passive clustering with ODMRP.
`ODMRP-CLUSTER-TIMEOUT` *Optional* *Scope:* All	Time *Range:* `> 0S` *Default:* `10S`	Specifies the timeout for maintaining clusters. **Note:** This option is used only when passive-clustering is enabled.
`TRACE-ODMRP` *Optional* *Scope:* Global, Node	List: • `YES` • `NO` *Default:* `NO`	Indicates whether packet tracing is enabled for ODMRP. **Note:** To enable packet tracing, some other parameters need to be configured as well. Refer to Section 4.2.10 of *EXata User's Guide* for details.

6.1.4 GUI Configuration

This section describes how to configure the ODMRP model in the GUI.

Configuring Multicast Groups

Refer to *EXata User's Guide* for details of configuring multicast groups using the Multicast Group Editor.

Configuring On-Demand Multicast Routing Protocol Parameters

To configure the ODMRP parameters, perform the following steps:

1. Go to one of the following locations:

- To set properties for a specific wireless subnet, go to **Wireless Subnet Properties Editor > Routing Protocol**.
- To set properties for a specific wired subnet, go to **Wired Subnet Properties Editor > Routing Protocol**.
- To set properties for a specific point-to-point link, go to **Point-to-point Link Properties Editor > Point-to-point Link Properties > Routing Protocol**.
- To set properties for a specific node, go to **Default Device Properties Editor > Node Configuration > Routing Protocol**.
- To set properties for a specific interface of a node, go to one of the following locations:
  - **Interface Properties Editor > Interfaces > Interface # > Routing Protocol**.
  - **Default Device Properties Editor > Interfaces > Interface # Routing Protocol**.

In this section, we show how to configure the model parameters for a specific node using the Default Device Properties Editor. Parameters can be set in the other properties editors in a similar way.

2. Set **Enable Multicast** to *Yes*.

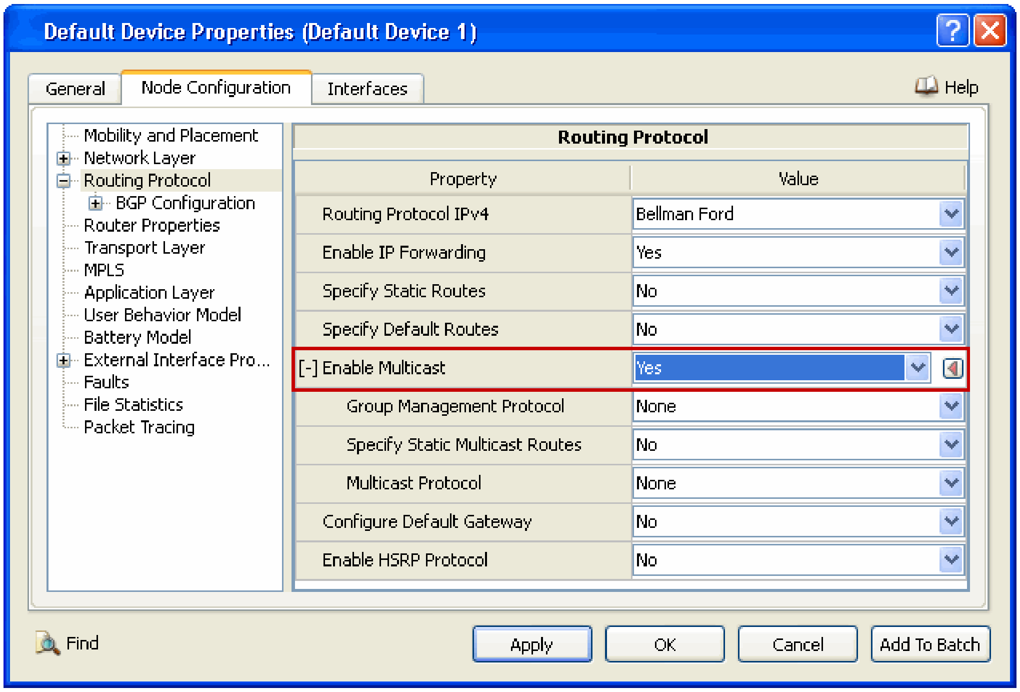


FIGURE 6-1. Enabling Multicast

3. Set **Multicast Protocol** to *ODMRP* and set the dependent parameters listed in Table 6-2.

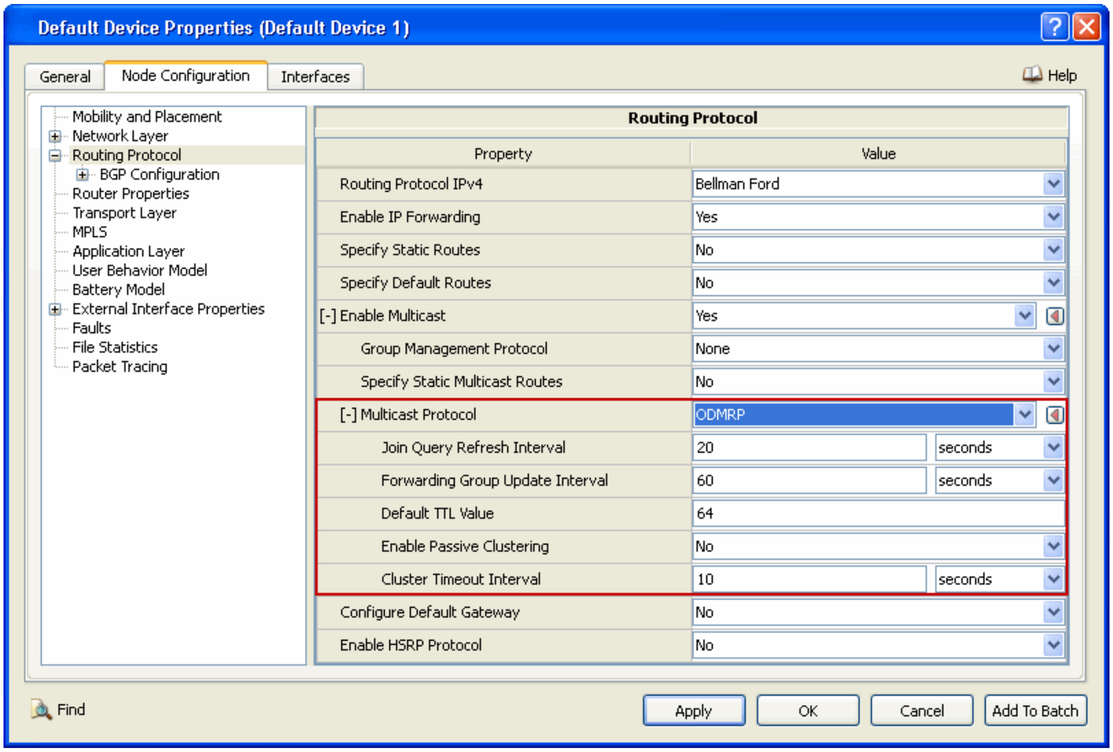


FIGURE 6-2. Setting ODMRP Parameters

TABLE 6-2. Command Line Equivalent of ODMRP Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Join Query Refresh Interval	Node, Subnet, Interface	`ODMRP-JR-REFRESH`
Forwarding Group Update Interval	Node, Subnet, Interface	`ODMRP-FG-TIMEOUT`
Default TTL Value	Node, Subnet, Interface	`ODMRP-DEFAULT-TTL`
Enable Passive Clustering	Node, Subnet, Interface	`ODMRP-PASSIVE-CLUSTERING`
Cluster Timeout Interval	Node, Subnet, Interface	`ODMRP-CLUSTER-TIMEOUT`

Setting Parameters

- To use Passive Clustering with ODMRP, set **Enable Passive Clustering** to *Yes*; otherwise, set **Enable Passive Clustering** to *No*.
- Cluster Timeout Interval is used only when Passive Clustering is enabled.

Configuring Statistics Parameters

Statistics for ODMRP can be collected at the global and node levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for routing protocols including ODMRP, check the box labeled **Routing** in the appropriate properties editor.

TABLE 6-3. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Routing	Global, Node	`ROUTING-STATISTICS`

Configuring Packet Tracing Parameters

Packet tracing for ODMRP can be enabled at the global and node levels. To enable packet tracing for ODMRP, in addition to setting the ODMRP trace parameter, **Trace ODMRP**, several other trace parameters also need to be set. See Section 4.2.10 of *EXata User's Guide* for details of configuring packet tracing parameters.

TABLE 6-4. Command Line Equivalent of Packet Tracing Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Trace ODMRP	Global, Node	`TRACE-ODMRP`

6.1.5 Statistics

Table 6-5 shows the ODMRP statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 6-5. ODMRP Statistics Collected

Statistic	Description
Join Queries Originated	Number of Join Queries originated.
Join Queries Transmitted	Number of Join Query (with piggybacked stat) packets transmitted.
Join Replies Sent	Number of Join Reply packets sent.
Join Replies Forwarded	Total number of Join Replies forwarded.
Join Replies retransmitted	Total number of Join Replies retransmitted.
ACKs Sent	Total number of ACK packets sent.
Data Packets Relayed	Total Number of ODMRP data packets relayed.
Data Packets Sent as Data Source	Total number of data packets sent as the source of the data.
Data Packets Received	Total number of data packets received as the destination of the data.
Total GiveUp Messages Sent	Total number of Give Up messages transmitted. This statistic is printed only when passive clustering is enabled.
Total GiveUp Messages Received	Total number of Give Up messages received. This statistic is printed only when passive clustering is enabled.

6.1.6 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the ODMRP model. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/odmrp. Table 6-6 lists the sub-directory where each scenario is located.

TABLE 6-6. ODMRP Scenarios Included in EXata

Scenario	Description
acknowledgement/without-pc	Shows that if a particular source is not a forwarding node for other sources, then the source must send an active acknowledgment to the previous hop.
acknowledgement/with-pc	Shows that if a particular source is not a forwarding node for other sources, then the source must send an active acknowledgment to the previous hop.
fault-handling/without-pc	Shows how program behaves if a node failure occurs in a time-interval during communication.
fault-handling/with-pc	Shows how the program behaves if a node failure occurs in a time-interval during communication.
passive-clustering	Shows that a node which first declares itself as Cluster Head cannot be overwritten by another node in Passive clustering.
query/without-pc	Shows that while outgoing data packets exist, the source sends Join Query every REFRESH_INTERVAL interval.
query/with-pc	Shows that while outgoing data packets exist, the source sends Join Query every REFRESH_INTERVAL interval.
reply/without-pc	Shows how a multicast receiver originates and broadcasts Join Reply after receiving a Join Query from multicast source, sets the next Hop address in Join Reply message which is the address of the node from which it has received the Join Query.
reply/with-pc	Shows how a multicast receiver originates and broadcasts Join Reply after receiving a Join Query from multicast source, sets the next Hop address in Join Reply message which is the address of the node from which it has received a Join Query.

6.1.7 References

1. draft-yi-manet-pc-00. "Passive Clustering in Ad Hoc Networks." Yunjung Yi, Taek Jin Kwon, Mario Gerla. November 14, 2001.
2. draft-ietf-manet-odmrp-02. "On-Demand Multicast Routing Protocol (ODMRP) for Ad Hoc Networks." Sung-Ju Lee, William Su, Mario Gerla. January 2000.
3. draft-ietf-manet-odmrp-04. "On-Demand Multicast Routing Protocol (ODMRP) for Ad Hoc Networks." Yunjung Yi, Sung-Ju Lee, William Su, Mario Gerla. November 2002.

7 Multi-layer Models

This chapter describes features, configuration requirements and parameters, statistics, and scenarios for the multi-layer models in the Satellite Model Library, and consists of the following sections:

- Aloha Satellite Model with RSV Support (Satellite-RSV)

7.1 Aloha Satellite Model with RSV Support (Satellite-RSV)

The EXata Satellite-RSV is based on the ETSI DVB-S standard.

7.1.1 Description

The Aloha Satellite Model with Reed-Solomon/Viterbi (RSV) support is a Demand Assignment Multiple Access (DAMA) scheme based on the Aloha protocol. The model operates either as a bent-pipe satellite or as a satellite with an onboard processor-payload.

The fundamental model of the system is a bidirectional burst-based transmission utilizing an outer Reed-Solomon (RS) with concatenated Viterbi inner convolutional code (RSV). This includes accounting for coding and modulation overhead, addition of ramp-up/ramp-down guard times, and preamble insertion.

Additionally the model also allows the user to specify interference levels from adjacent channels and adjacent satellites and cross-polarization energy leakage.

The Aloha Satellite model consists of the Satellite-RSV PHY and MAC models which are intended to be used in conjunction. The channel simulation of the satellite uses standard EXata propagation modeling and therefore can be configured to model satellite movement using the EXata mobility file option.

7.1.2 Features and Assumptions

This section describes the implemented features, omitted features, assumptions and limitations of the Satellite-RSV model.

7.1.2.1 Implemented Features

- Both bent-pipe and processing payload functionality.
- RS-V models for frame size and decoding capability.
- Separate uplink and downlink support using standard EXata channel model.

7.1.2.2 Omitted Features

- Advanced DAMA: The existing method has a low efficiency and requires more algorithms to schedule the transmissions on the satellite network effectively.
- BER Curves: No BER curves are included in this model and a cliff 7 dB Eb/No is assumed. The actual Eb/No requirement depend on the type of coding being used.

7.1.2.3 Assumptions and Limitations

None.

7.1.3 Supplemental Information

None.

7.1.4 Command Line Configuration

To specify Satellite-RSV and the PHY model and MAC protocol, include the following parameters in the scenario configuration (.config) file:

```
[<Qualifier>]   PHY-MODEL                   SATELLITE-RSV
[<Qualifier>]   MAC-PROTOCOL                SATELLITE-BENTPIPE
```

The scope of this parameter declaration can be Global, Node, Subnet, or Interface. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

Satellite-RSV Parameters

Table 7-1 lists the Satellite-RSV PHY configuration parameters and Table 7-2 lists the Satellite-RSV MAC configuration parameters specified in the scenario configuration (.config) file. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 7-1. Satellite-RSV PHY Parameters

Parameter	Value	Description
PHY-SATELLITE-RSV-CHANNEL-BANDWIDTH *Optional* *Scope:* All	Real *Range:* > 0 *Default:* 1280000 *Unit:* Hz	Specifies the bandwidth of transmission channel. This is the net channel rate after filtering, shaping and other overheads are removed.
PHY-SATELLITE-RSV-PREAMBLE-SIZE *Optional* *Scope:* All	Integer *Range:* > 0 (see note) *Default:* 64 *Unit:* bits	Specifies the preamble size for transmission. This is directly added to the coded packet size for transmission. **Note:** PHY-SATELLITE-RSV-PREAMBLE-SIZE should not be a multiple of 8.
PHY-SATELLITE-RSV-USE-SHORTEN-LAST-CODEWORD *Optional* *Scope:* All	List: • TRUE/YES • FALSE/NO *Default:* YES	Specifies whether the RS encoder should shorten the last Reed-Solomon codeword in a transmission to make the block coding more efficient. If the parameter is set to TRUE or YES, the RS encoder shortens the last RS codeword to the minimum size for data blocks less than 188 symbols.
PHY-SATELLITE-RSV-BLOCK-CODING *Optional* *Scope:* All	List: • REED-SOLOMON-204-188 *Default:* REED-SOLOMON-204-188	Specifies the type of outer block coding supported by the system. Only the (204,188) GF(256) scheme is supported.

TABLE 7-1. Satellite-RSV PHY Parameters (Continued)

Parameter	Value	Description
PHY-SATELLITE-RSV-TRANSMIT-POWER *Required* *Scope:* All	Real *Range:* ≥ 0 *Unit:* mw	Specifies the transmitter power for the user-defined transmitter. This is a required parameter if PHY-SATELLITE-RSV-TRANSMISSION-MODE is set as USER-DEFINED.
PHY-SATELLITE-RSV-SENSITIVITY *Required* *Scope:* All	Real *Unit:* dBm	Specifies the sensitivity of the user defined receiver. This is a required parameter if PHY-SATELLITE-RSV-TRANSMISSION-MODE is set as USER-DEFINED.
PHY-SATELLITE-RSV-BITS-PER-SYMBOL *Required* *Scope:* All	Real *Range:* ≥ 1	Specifies the number of bits per symbol transmitted by the user defined modulator. This is a required parameter if PHY-SATELLITE-RSV-TRANSMISSION-MODE is set as USER-DEFINED.
PHY-SATELLITE-RSV-TRANSMISSION-MODE *Optional* *Scope:* All	List: • BPSK • QPSK • 8PSK • USER-DEFINED *Default:* BPSK	Specifies the type of digital modulation to be used in the system. **Note:** Not all modulation profiles can be used with all convolutional codes. See PHY-SATELLITE-RSV-CONVOLUTIONAL-CODING for more information.
PHY-SATELLITE-RSV-CONVOLUTIONAL-CODING *Optional* *Scope:* All	List: • VITERBI-1-2 • VITERBI-2-3 • VITERBI-3-4 • VITERBI-5-6 • VITERBI-7-8 • VITERBI-8-9 *Default:* VITERBI-1-2	Specifies the convolutional coding scheme to be used for the inner code of the digital communications layer. 8PSK supports only VITERBI-2-3, VITERBI-5-6, and VITERBI-8-9. QPSK supports only VITERBI-1-2, VITERBI-3-4, and VITERBI-7-8. BPSK supports all modes.

TABLE 7-1. Satellite-RSV PHY Parameters (Continued)

Parameter	Value	Description
`PHY-SATELLITE-RSV-GUARD-TIME` *Optional* *Scope:* All	Time *Range:* ≥ `0S` *Default:* `10US`	Specifies the amount of time to be used the guard time interval in the TDMA system. This amount of time is added to each transmission to account for ramp-up, ramp-down, and other communications effects during transmission.
`PHY-SATELLITE-RSV-ADJACENT-CHANNEL-INTERFERENCE` *Optional* *Scope:* All	Real *Default:* `18` *Unit:* - dBc	Specifies the average level of adjacent channel interference imposed on the current channel by all other channels in the system. Note that the unit of this parameter is - dBc. For example, if channel interference is -20 dBc, it should be specified in the configuration file as: `PHY-SATELLITE-RSV-ADJACENT-CHANNEL-INTERFERENCE 20`
`PHY-SATELLITE-RSV-ADJACENT-SATELLITE-INTERFERENCE` *Optional* *Scope:* All	Real *Default:* `30` *Unit:* - dBc	Specifies the adjacent channel interference imposed on the current channel by all other satellites using the same channel in the system. Note that the unit of this parameter is - dBc. For example, if satellite interference is -20 dBc, it should be specified in the configuration file as: `PHY-SATELLITE-RSV-ADJACENT-SATELLITE-INTERFERENCE 20`
`PHY-SATELLITE-RSV-INTERMODULATION-INTERFERENCE` *Optional* *Scope:* All	Real *Default:* `25` *Unit:* - dBc	Specifies the amount of inter-modulation interference that is caused by non linearity in the transmission ampler stages. It is measured in dBc and should be the nominal value at the peak operating point of the amplifier. Note that the unit of this parameter is - dBc. For example, if inter-modulation interference is -20 dBc, it should be specified in the configuration file as: `PHY-SATELLITE-RSV-INTERMODULATION-INTERFERENCE 20`
`PHY-SATELLITE-RSV-EBNO-THRESHOLD` *Optional* *Scope:* All	Real *Default:* `7` *Unit:* dB	Specifies the level of power per user (uncoded) bit scaled by the noise of the system. If the reception signal level is higher than this threshold, the packet is received without error. If it is lower, then the packet is marked as having data errors.

TABLE 7-2. Satellite-RSV MAC Parameters

Parameter	Value	Description
MAC-SATELLITE-BENTPIPE-ROLE *Optional* *Scope:* All	List: • GROUND-STATION • SATELLITE *Default:* GROUND-STATION	Specifies the type of satellite system.
SATELLITE-CHANNEL-COUNT *Optional* *Scope:* All	Integer *Range:* > 0	Specifies the number of channels configured on the satellite node. **Note:** This is a required parameter if MAC-SATELLITE-BENTPIPE-ROLE is set to SATELLITE.
SATELLITE-UPLINK-CHANNEL *Optional* *Scope:* All *Instances:* uplink channel index	Integer or string *Range:* ≥ 0 (if channel index is used)	Specifies the index or name of the uplink channel for the satellite node. **Note:** This is a required parameter if MAC-SATELLITE-BENTPIPE-ROLE is set as SATELLITE.
SATELLITE-DOWNLINK-CHANNEL *Optional* *Scope:* All *Instances:* downlink channel index	Integer or string *Range:* ≥ 0 (if channel index is used)	Specifies the index or name of the downlink channel for the satellite node. **Note:** his is a required parameter if MAC-SATELLITE-BENTPIPE-ROLE is set as SATELLITE.
SATELLITE-USE-UPLINK-CHANNEL *Optional* *Scope:* All	Integer or string *Range:* ≥ 0 (if channel index is used)	Specifies the index or name of the uplink channel that the GROUND-STATION node will use. **Note:** This is a required parameter if MAC-SATELLITE-BENTPIPE-ROLE is set as GROUND-STATION.
SATELLITE-USE-DOWNLINK-CHANNEL *Optional* *Scope:* All	Integer or string *Range:* ≥ 0 (if channel index is used)	Specifies the index or name of the downlink channel that the GROUND-STATION node will use. **Note:** This is a required parameter if MAC-SATELLITE-BENTPIPE-ROLE is set as GROUND-STATION.

TABLE 7-2. Satellite-RSV MAC Parameters

Parameter	Value	Description
MAC-SATELLITE-BENTPIPE-FORWARD-TO-PAYLOAD-PROCESSOR *Optional* *Scope:* All	List: • YES • NO *Default:* FNO	Specifies the switching capability of the satellite. If the parameter is set to YES or TRUE, the payload is sent to the network process; otherwise, it is retransmitted directly.
MAC-SATELLITE-BENTPIPE-TRANSMIT-POWER-MW *Optional* *Scope:* All	Real *Range:* ≥ 0 *Default:* 3000 *Unit:* mW	Specifies the transmit power of the satellite (in mW).

Examples of Parameter Usage

```
[N16-0] MAC-PROTOCOL SATELLITE-BENTPIPE
[N16-0] PHY-MODEL[0] SATELLITE-RSV
[N16-0] PHY-SATELLITE-EBNO-THRESHOLD 7.0
[N16-0] MAC-SATELLITE-BENTPIPE-FORWARD-TO-PAYLOAD-PROCESSOR FALSE
[N16-0] MAC-SATELLITE-BENTPIPE-TRANSMIT-POWER-MW 7000
[N16-0] PHY-SATELLITE-RSV-CHANNEL-BANDWIDTH 320.0e3
[N16-0] PHY-SATELLITE-RSV-PREAMBLE-SIZE 64
[N16-0] PHY-SATELLITE-RSV-USE-SHORTEN-LAST-CODEWORD TRUE
[N16-0] PHY-SATELLITE-RSV-BLOCK-CODING REED-SOLOMON-204-188
[N16-0] PHY-SATELLITE-RSV-TRANSMISSION-MODE BPSK
[N16-0] PHY-SATELLITE-RSV-CONVOLUTIONAL-CODING VITERBI-1-2
[N16-0] PHY-SATELLITE-RSV-GUARD-TIME 10US
[N16-0] PHY-SATELLITE-ADJACENT-CHANNEL-INTERFERENCE 20.0
[N16-0] PHY-SATELLITE-ADJACENT-SATELLITE-INTERFERENCE 25.0

[1] MAC-SATELLITE-BENTPIPE-ROLE SATELLITE
[1] PHY-SATELLITE-RSV-INTERMODULATION-INTERFERENCE 18.0
[2 thru 3] MAC-SATELLITE-BENTPIPE-ROLE GROUND-STATION
[2 thru 3] PHY-SATELLITE-RSV-INTERMODULATION-INTERFERENCE 30.0
[1] SATELLITE-CHANNEL-COUNT 4


[1] SATELLITE-UPLINK-CHANNEL[0]   0
[1] SATELLITE-DOWNLINK-CHANNEL[0]   2

[1] SATELLITE-UPLINK-CHANNEL[1]   1
[1] SATELLITE-DOWNLINK-CHANNEL[1]   3

[2] SATELLITE-USE-UPLINK-CHANNEL 0
[2] SATELLITE-USE-DOWNLINK-CHANNEL 2
[3] SATELLITE-USE-UPLINK-CHANNEL 1
[3] SATELLITE-USE-DOWNLINK-CHANNEL 3
```

7.1.5 GUI Configuration

This section describes how to configure Aloha Satellite Model with RSV Support (Satellite-RSV) in the GUI. Section 7.1.5.1 describes how to configure Satellite-RSV parameters at the MAC layer, and Section 7.1.5.3 describes how to configure Satellite-RSV parameters at the PHY layer.

Satellite and Ground Station Devices

In the GUI, Satellite RSV is modeled by the Satellite RSV subnet in the Network Components toolbar of the Standard Toolset.

FIGURE 7-1. Satellite RSV Device in Network Components Toolbar

Ground stations can be modeled by the Default Device or the Ground Station Device in the Devices toolbar of the Standard Toolset.

FIGURE 7-2. Ground Station Device in Devices Toolbar

7.1.5.1 Configuring Satellite-RSV Parameters at the PHY Layer

To configure the Aloha Satellite Model with RSV Support (Satellite-RSV) parameters at the PHY level, perform the following steps:

1. Go to one of the following locations:

- To set properties for a specific subnet, go to **Wireless Subnet Properties Editor > PHY Layer**.
- To set properties a specific interface of a node, go to one of the following locations:
  - **Interface Properties Editor > Interfaces > Interface # > PHY Layer**.
  - **Default Device Properties Editor > Interfaces > Interface # > PHY Layer**.

In this section, we show how to configure the Satellite-RSV general parameters in the Wireless Subnet Properties editor. Parameters can be set in the other properties editors in a similar way.

2. Set **Radio Type** to *Satellite-RSV PHY* and set the dependent parameters listed in Table 7-3.

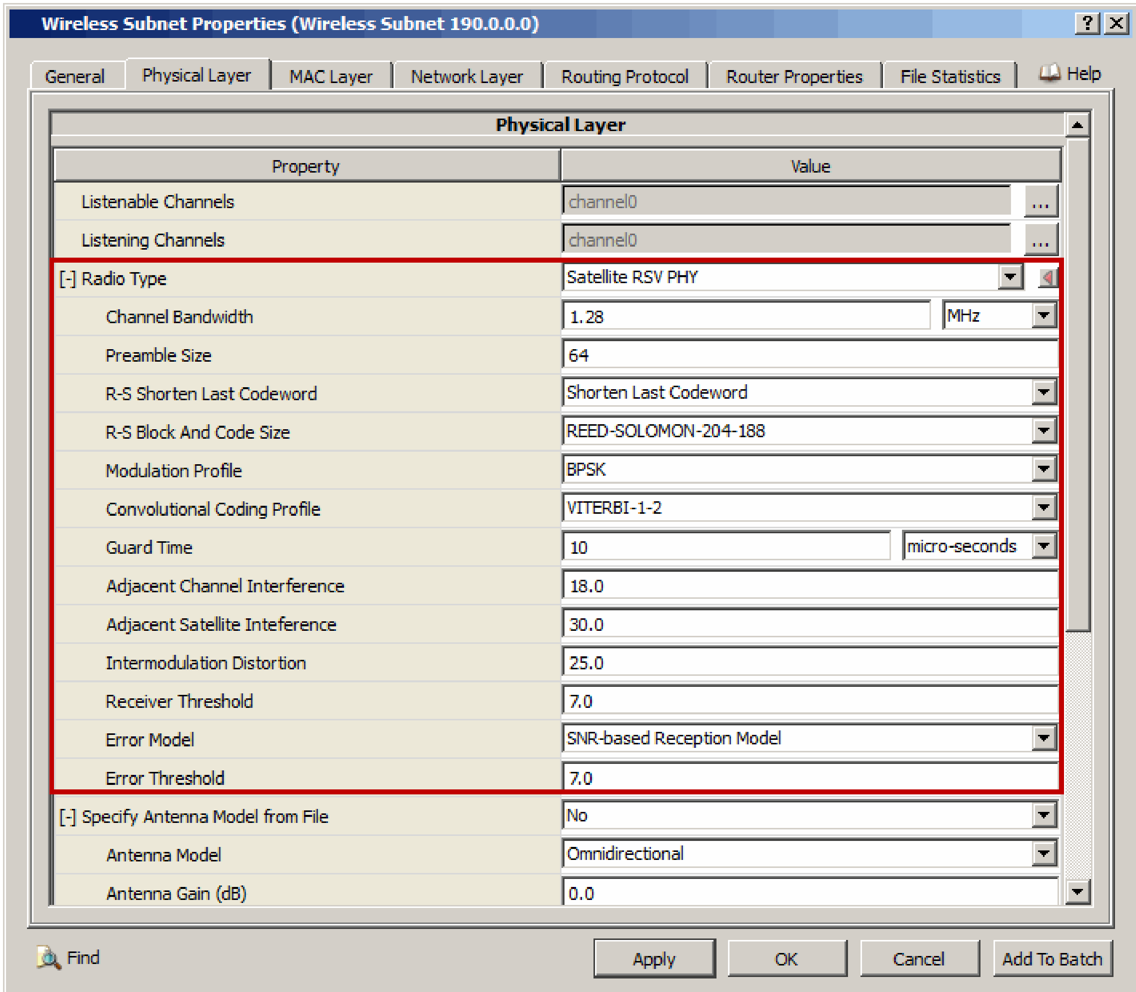


FIGURE 7-3. Setting Satellite-RSV PHY Parameters

TABLE 7-3. Command Line Equivalent of Satellite-RSV PHY Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Channel Bandwidth	Subnet, Interface	`PHY-SATELLITE-RSV-CHANNEL-BANDWIDTH`
Preamble Size	Subnet, Interface	`PHY-SATELLITE-RSV-PREAMBLE-SIZE`
R-S Shorten Last Codeword	Subnet, Interface	`PHY-SATELLITE-RSV-USE-SHORTEN-LAST-CODEWORD`
R-S Block And Code Size	Subnet, Interface	`PHY-SATELLITE-RSV-BLOCK-CODING`
Modulation Profile	Subnet, Interface	`PHY-SATELLITE-RSV-TRANSMISSION-MODE`

TABLE 7-3. Command Line Equivalent of Satellite-RSV PHY Parameters (Continued)

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Convolutional Coding Profile	Subnet, Interface	PHY-SATELLITE-RSV-CONVOLUTIONAL-CODING
Guard Time	Subnet, Interface	PHY-SATELLITE-RSV-GUARD-TIME
Adjacent Channel Interference	Subnet, Interface	PHY-SATELLITE-RSV-ADJACENT-CHANNEL-INTERFERENCE
Adjacent Satellite Interference	Subnet, Interface	PHY-SATELLITE-RSV-ADJACENT-SATELLITE-INTERFERENCE
Intermodulation Distortion	Subnet, Interface	PHY-SATELLITE-RSV-INTERMODULATION-INTERFERENCE
Receiver Threshold	Subnet, Interface	PHY-SATELLITE-RSV-EBNO-THRESHOLD
Error Model	Subnet, Interface	PHY-RX-MODEL
Error Threshold	Subnet, Interface	PHY-RX-SNR-THRESHOLD

7.1.5.2 Configuring Satellite-RSV Parameters at the MAC Layer

To configure the Aloha Satellite Model with RSV Support (Satellite-RSV) parameters at the MAC layer, perform the following steps:

1. Place a Bentpipe Satellite Subnet and a Ground Station node on the canvas.
2. Add a link between the Bentpipe Satellite Subnet and the Ground Station node.
3. Go to one of the following locations:
   - To set properties for a specific subnet, go to **Wireless Subnet Properties Editor > MAC Layer**.
   - To set properties a specific interface of a node, go to one of the following locations:
     - **Interface Properties Editor > Interfaces > Interface # > MAC Layer**.
     - **Default Device Properties Editor > Interfaces > Interface # > MAC Layer**.

In this section, we show how to configure the Satellite-RSV general parameters in the Wireless Subnet Properties editor. Parameters can be set in the other properties editors in a similar way.

4. Set **MAC Protocol** to *Satellite-RSV MAC* and set the dependent parameters listed in Table 7-4.

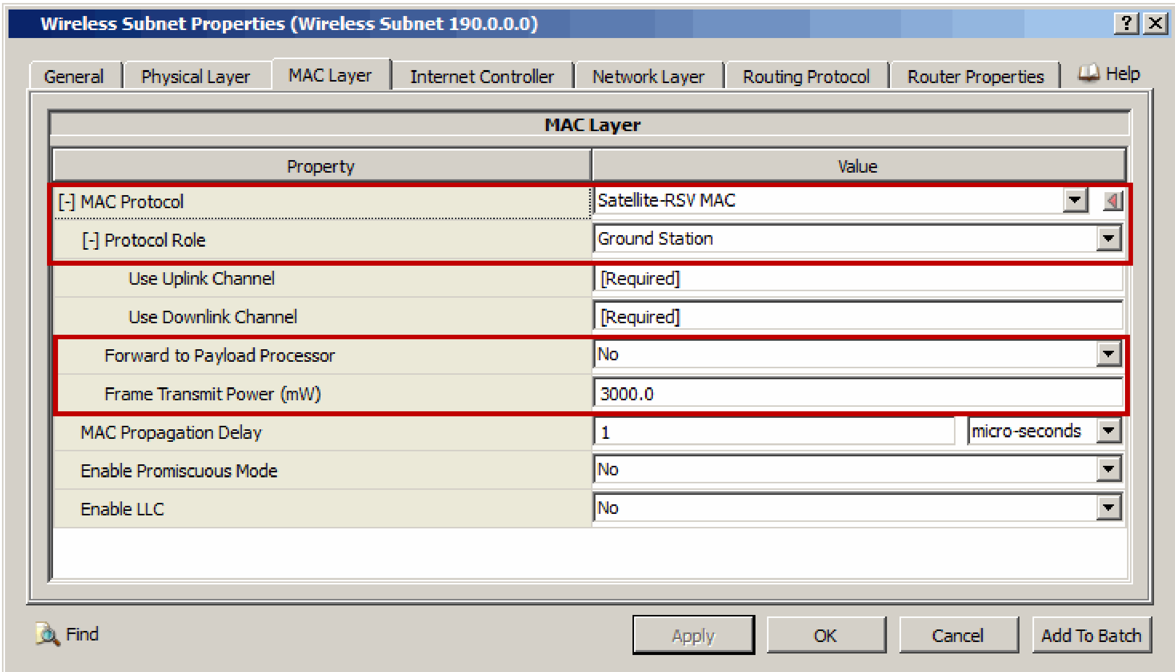


FIGURE 7-4. Setting Satellite-RSV MAC Parameters

TABLE 7-4. Command Line Equivalent of Satellite-RSV MAC Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Protocol Role	Subnet, Interface	MAC-SATELLITE-BENTPIPE-ROLE
Forward to Payload Processor	Subnet, Interface	MAC-SATELLITE-BENTPIPE-FORWARD-TO-PAYLOAD-PROCESSOR
Frame Transmit Power	Subnet, Interface	MAC-SATELLITE-BENTPIPE-TRANSMIT-POWER-MW

Setting Parameters

- To send the payload to the network process, set **Forward to Payload Processor** to *Yes*, otherwise set **Forward to Payload Processor** to *No*.

5. If **Protocol Role** is set to *Ground Station*, then set the dependent parameters listed in Table 7-4.

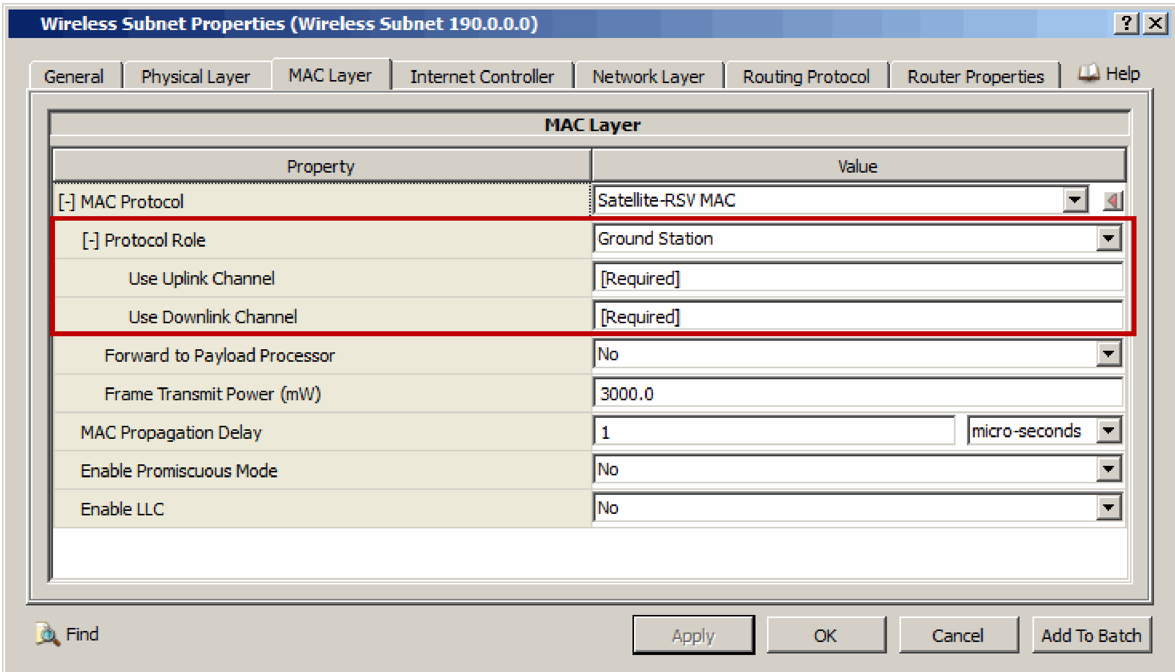


FIGURE 7-5. Setting Ground Station Parameters

TABLE 7-5. Command Line Equivalent of Ground Station Parameter

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Use Uplink Channel	Subnet, Interface	`SATELLITE-USE-UPLINK-CHANNEL`
Use Downlink Channel	Subnet, Interface	`SATELLITE-USE-DOWNLINK-CHANNEL`

6. If **Protocol Role** is set to *Satellite*, then set the dependent parameters listed in Table 7-6.

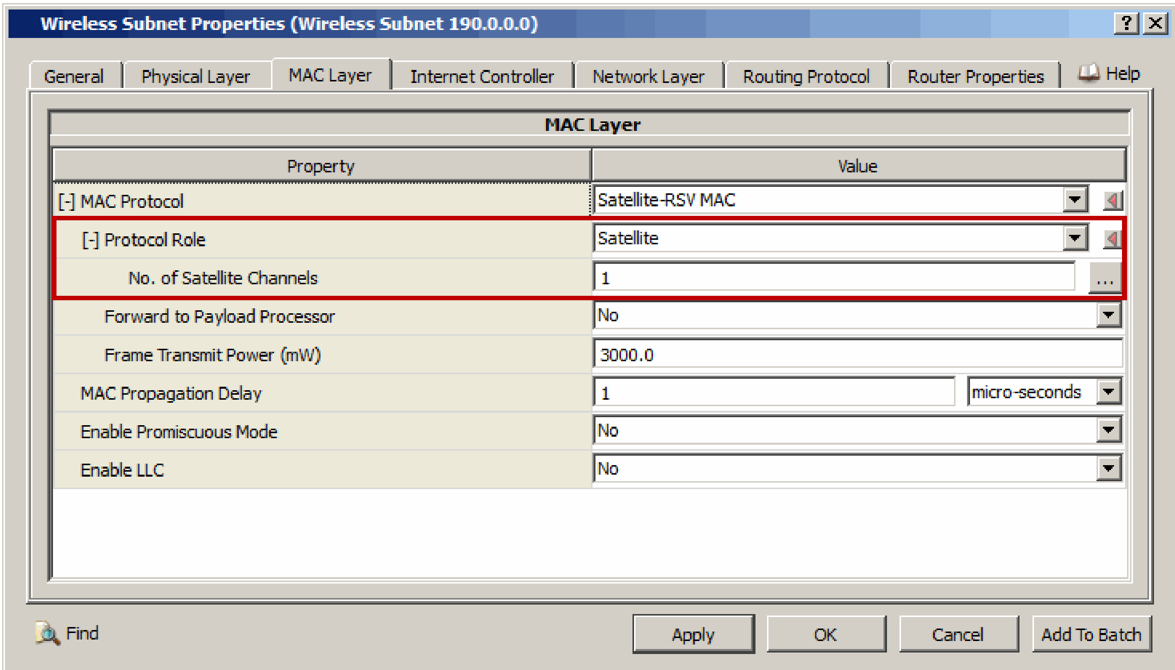


FIGURE 7-6. Setting Satellite Parameters

TABLE 7-6. Command Line Equivalent of Satellite Parameter

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
No. of Satellite Channels	Subnet, Interface	`SATELLITE-CHANNEL-COUNT`

7. Set **No. of Satellite Channels** to the number of pairs of uplink/downlink channels in the scenario and configure the channel properties as follows:

   a. Click the **Open Array Editor** ... button in the **Value** column. This opens the Array Editor (see Figure 7-7).

   b. In the left panel of the Array Editor, select the index of the channel to be configured. In the right panel, set the parameters listed in Table 7-7.

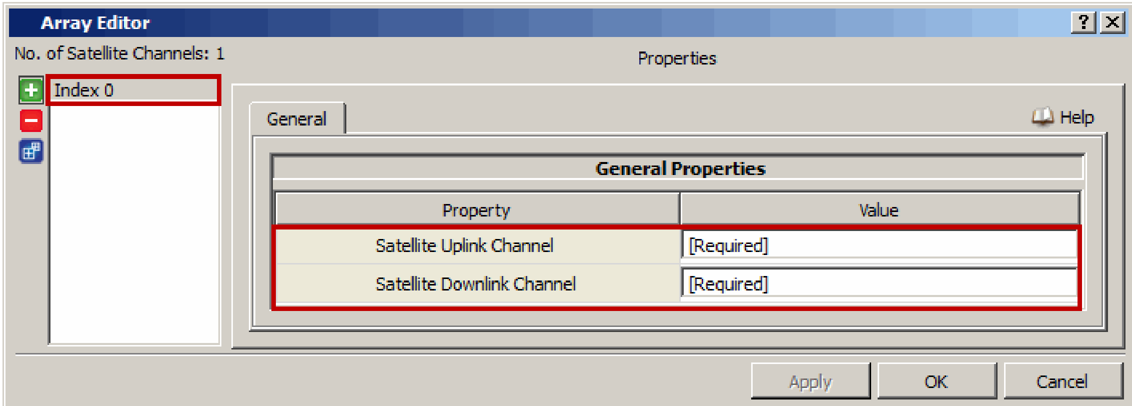


FIGURE 7-7. Setting Channel Parameters for Bentpipe Satellite

TABLE 7-7. Command Line Equivalent of Channel Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Satellite Uplink Channel	Subnet, Interface	`SATELLITE-UPLINK-CHANNEL`
Satellite Downlink Channel	Subnet, Interface	`SATELLITE-DOWNLINK-CHANNEL`

7.1.5.3 Statistics

Table 7-8 and Table 7-9 lists the statistics collected for the Satellite-RSV model that are output to the statistics (.stat) file at the end of simulation.

TABLE 7-8. Satellite-RSV PHY Statistics

Statistic	Description
Signals transmitted	Number of signals transmitted by this physical layer process.
Signals received and forwarded to MAC	Number of signals received by this physical layer process and subsequently forwarded to the MAC layer for further processing.
Signals locked on by PHY	Number of signals that triggered logic to lock the transceiver onto an incoming signal.
Signals received but with errors	Number of signals received that were successfully received by the MAC but had errors due to interference or noise corruption.
Average Eb/No (dB)	Average EB/No of the channel

TABLE 7-9. Satellite-RSV MAC Statistics

Statistic	Description
UNICAST packets sent to the channel	Number of unicast packets sent to the channel
BROADCAST packets sent to the channel	Number of broadcast packets sent to the channel
UNICAST packets received from channel	Number of unicast packets received from the channel
BROADCAST packets received from channel	Number of broadcast packets received from the channel

7.1.6 Sample Scenario

7.1.6.1 Scenario Description

The scenario is composed of two ground systems which are located at the opposite ends of the continent. The two stations are going to exchange 25 UDP packets spaced one second apart from simulation times 1 to 25 seconds. The system will be routed via RIPv2 routing protocol.

There is a geosynchronous bent-pipe satellite located at nearly 109 degrees west longitude. This system operates near the top of the Ka-band on a channel located at 29.75 GHz.

Technical Aspects of Scenario

The system uses a concatenated Reed-Solomon Viterbi coding. The outer RS code is (204,188) and the inner code is chosen to be 1/2 using BPSK modulation. Transmission occurs via a SSPA on the ground that has an EIRP of roughly 49.0 dBW. The LNA has a low noise figure of 0.75 dB and the sky noise is set to 40K. The default channel width is 640 KHz for the main lobe.

Table 7-10 summarizes the changes to the simulation configuration to reflect the satellite digital communication environment.

TABLE 7-10. Digital Communication Parameters

Parameter Name	Value
`PHY-TEMPERATURE`	`40`
`PHY-NOISE-FACTOR`	`1.19`
`PHY-RX-MODEL`	`SNR-THRESHOLD-BASED`
`ANTENNA-GAIN`	`43`
`PROPAGATION-CHANNEL-FREQUENCY`	`29500000000`
`PROPAGATION-LIMIT`	`-150`

Topology

Figure 7-8 shows the scenario topology.

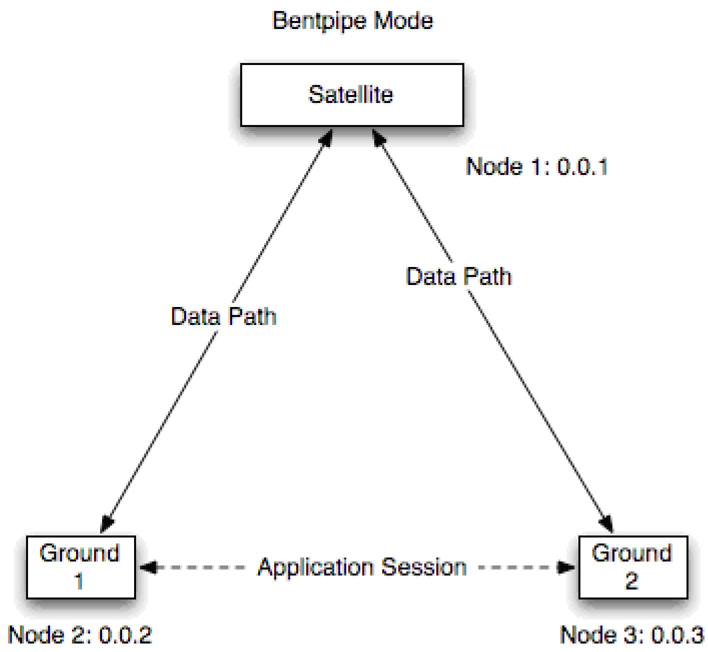


FIGURE 7-8. Sample Scenario Topology

7.1.6.2 Command Line Configuration

To configure the sample scenario, include the following lines in the scenario configuration (.config) file:

```
PHY-TEMPERATURE                                        40
PHY-NOISE-FACTOR                                       1.19
PHY-RX-MODEL                                          SNR-THRESHOLD-BASED
ANTENNA-GAIN                                           43
PROPAGATION-CHANNEL-FREQUENCY[0]                       29500000000
PROPAGATION-CHANNEL-NAME[0]                            channel-0
PROPAGATION-LIMIT                                      -150
SUBNET N16-0 { 1 thru 3 }
[N16-0] MAC-PROTOCOL                                    SATELLITE-BENTPIPE
[N16-0] PHY-LISTENABLE-CHANNELS                         channel-0
[N16-0] PHY-LISTENING-CHANNELS                          channel-0
[N16-0] PHY-MODEL[0]                                    SATELLITE-RSV
[1] MAC-SATELLITE-BENTPIPE-ROLE                         SATELLITE
[2 thru 3] MAC-SATELLITE-BENTPIPE-ROLE                  GROUND-STATION
[N16-0] MAC-SATELLITE-BENTPIPE-FORWARD-TO-PAYLOAD-PROCESSOR   FALSE
[N16-0] MAC-SATELLITE-BENTPIPE-TRANSMIT-POWER-MW              7000
[N16-0] PHY-SATELLITE-RSV-CHANNEL-BANDWIDTH                   320.0e3
[N16-0] PHY-SATELLITE-RSV-PREAMBLE-SIZE                       64
[N16-0] PHY-SATELLITE-RSV-USE-SHORTEN-LAST-CODEWORD           TRUE
[N16-0] PHY-SATELLITE-RSV-BLOCK-CODING          REED-SOLOMON-204-188
[N16-0] PHY-SATELLITE-RSV-TRANSMISSION-MODE      BPSK
[N16-0] PHY-SATELLITE-RSV-CONVOLUTIONAL-CODING   VITERBI-1-2
[N16-0] PHY-SATELLITE-RSV-GUARD-TIME             10US
[N16-0] PHY-SATELLITE-ADJACENT-CHANNEL-INTERFERENCE            20.0
[N16-0] PHY-SATELLITE-ADJACENT-SATELLITE-INTERFERENCE          25.0
[1] PHY-SATELLITE-RSV-INTERMODULATION-INTERFERENCE             18.0
[2 thru 3] PHY-SATELLITE-RSV-INTERMODULATION-INTERFERENCE      30.0
[N16-0] PHY-SATELLITE-EBNO-THRESHOLD                           7.0
```

7.1.6.3 GUI Configuration

The configure the sample scenario in the GUI, perform the following steps:

1. Go to **Scenario Properties > Channel Properties** and set **Number of Channels** as *4* and set different **Channel Frequencies** for each channel (e.g., 2.4 GHz, 2.6 GHz, 2.7 GHz, and 2.8 GHz) as shown in Figure 7-9.

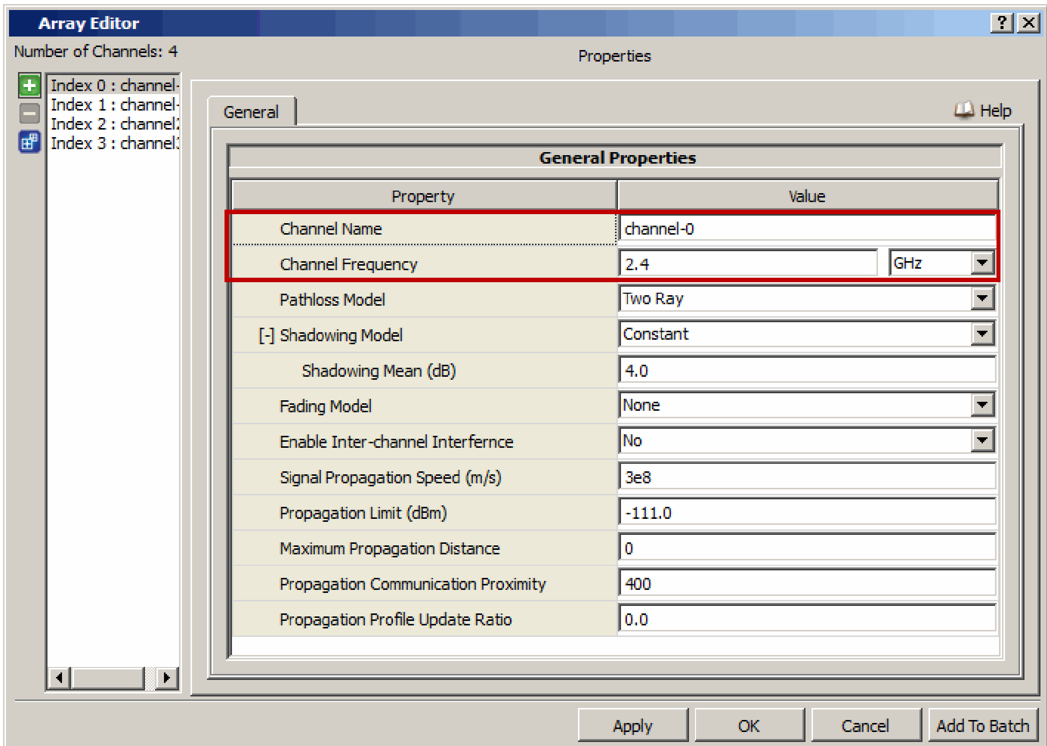


FIGURE 7-9. Array Editor with 4 Channels and Different Channel Frequencies

2. Place two **Ground Station**  devices and a **Bentpipe Satellite Subnet** . Connect the ground stations to the satellite.
3. For each ground station, go to **Default Device Properties Editor > Interfaces > Interface 0 > MAC Layer**.
   - **a.** Set **MAC Protocol** to *Satellite-RSV-MAC*.
   - **b.** Set **Protocol Role** to *Ground Station*.
   - **c.** Set **Use Uplink Channel** and **Use Downlink Channel** to *0* and *1*, respectively (for ground station 1) and to *2* and *3*, respectively (for ground station 2).
   - **d.** Use default values for the other parameters.

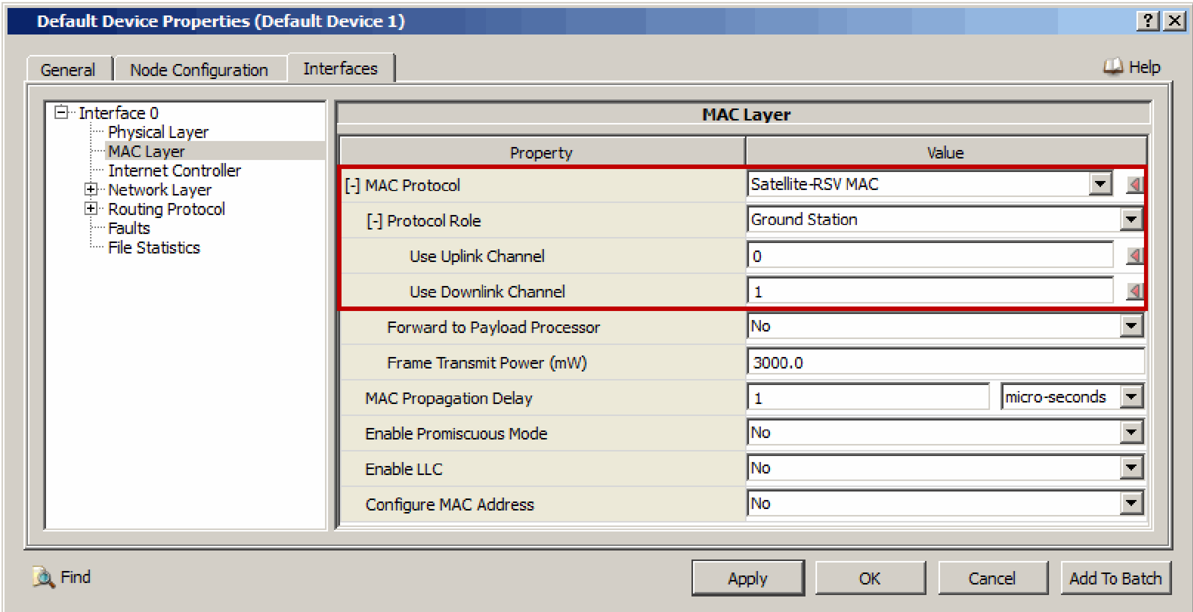


FIGURE 7-10. Setting Ground Station Parameters

4. For each ground station, go to **Default Device Properties Editor > Interfaces > Interface 0 > Physical Layer**.
   a. Set the **Radio Type** to *Satellite RSV PHY*.
   b. Set **Intermodulation Distortion** to *30.0*.
   c. Use default values for the other parameters.
5. For each ground station, go to **Default Device Properties Editor > Routing Protocol**.
   a. Set **Routing Protocol** to *None*.
   b. Set **Specify Static Routes** to *Yes* and specify the static routes file. Include the following in the static routes file:

```
1 190.0.1.2 190.0.1.2
2 190.0.1.1 190.0.1.1
```

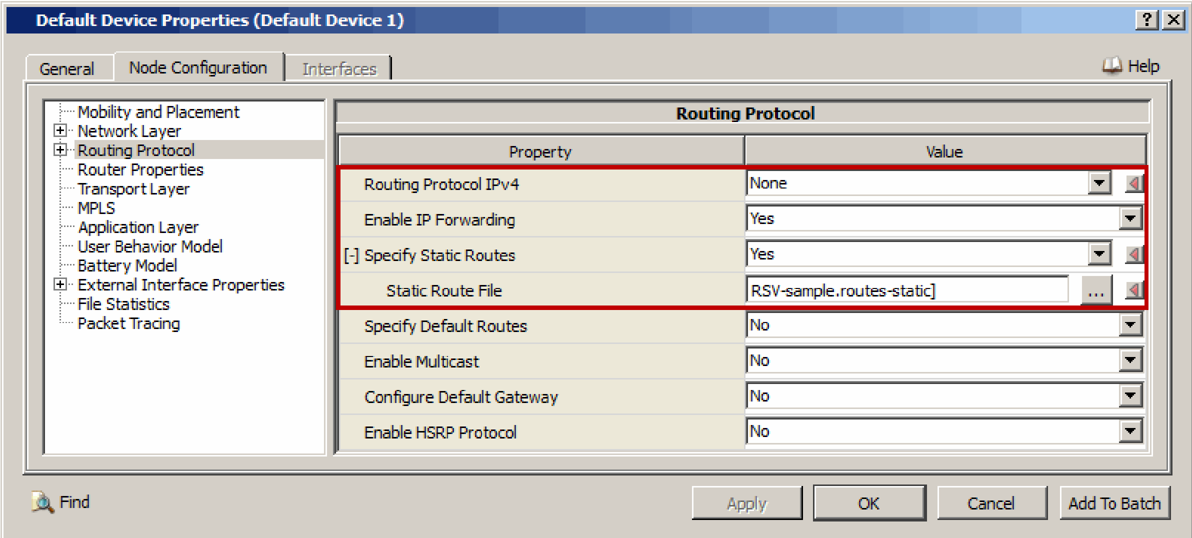


FIGURE 7-11. Setting Routing Protocol

6. For the satellite subnet, go to **Wireless Subnet Properties Editor > MAC Layer**.
   a. Set **MAC Protocol** to *Satellite-RSV-MAC*.
   b. Set **Protocol Role** to *Satellite*.
   c. Set **Frame Transmit Power** to *7000.0*.
   d. Set **No. of Satellite Channels** to *2*.

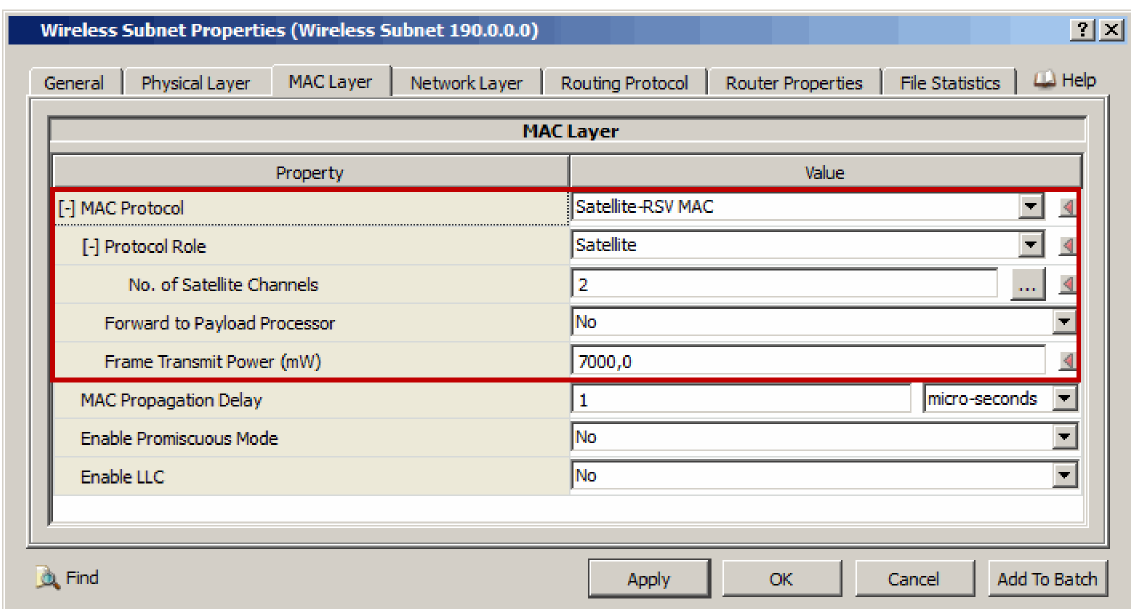


FIGURE 7-12. Setting Satellite Parameters

e. Open the Array Editor for these channels and set the **Satellite Uplink Channel** and **Satellite Downlink Channel** as follows:

- 0 and 1 for index 0 (as shown below)
- 2 and 3 for index 1

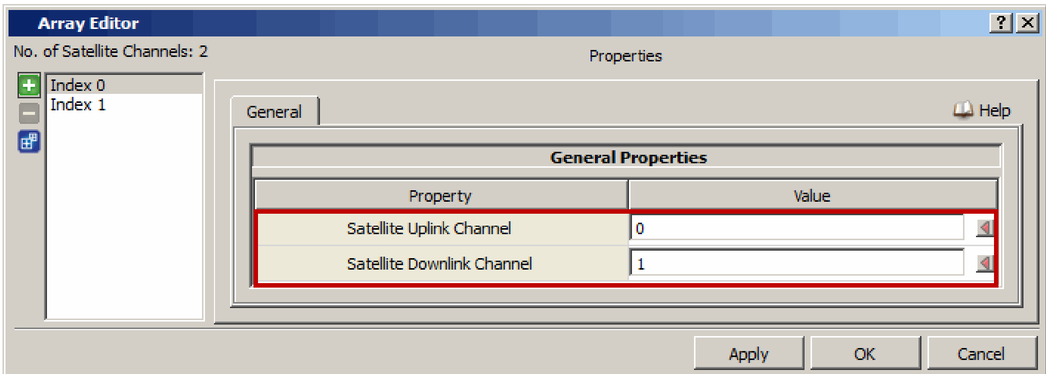


FIGURE 7-13. Setting Satellite Uplink and Downlink Channel Properties

f. Use default values for the other parameters.

7. For the satellite subnet, go to **Wireless Subnet Properties Editor > Physical Layer**.

a. Set the **Radio Type** to *Satellite RSV PHY*.

b. Set **Channel Bandwidth** to *320 KHz*.

c. Set **Intermodulation Distortion** to *18.0*.

d. Use default values for the other parameters.

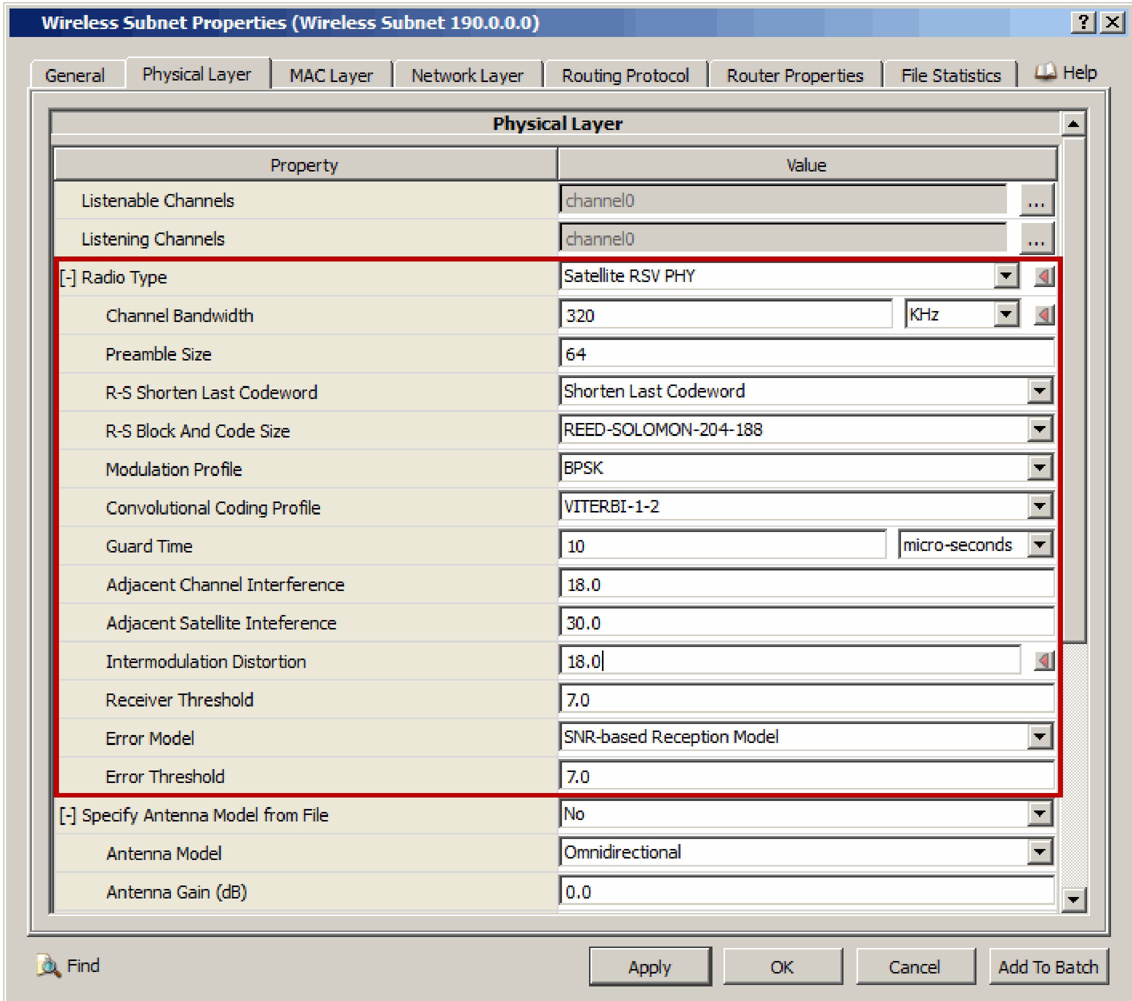


FIGURE 7-14. Physical Layer Configuration of Bentpipe Subnet

8. Add an application (e.g., CBR) from first ground station (node 1) to the second ground station (node 2). Then configure the parameters as shown Figure 7-15.

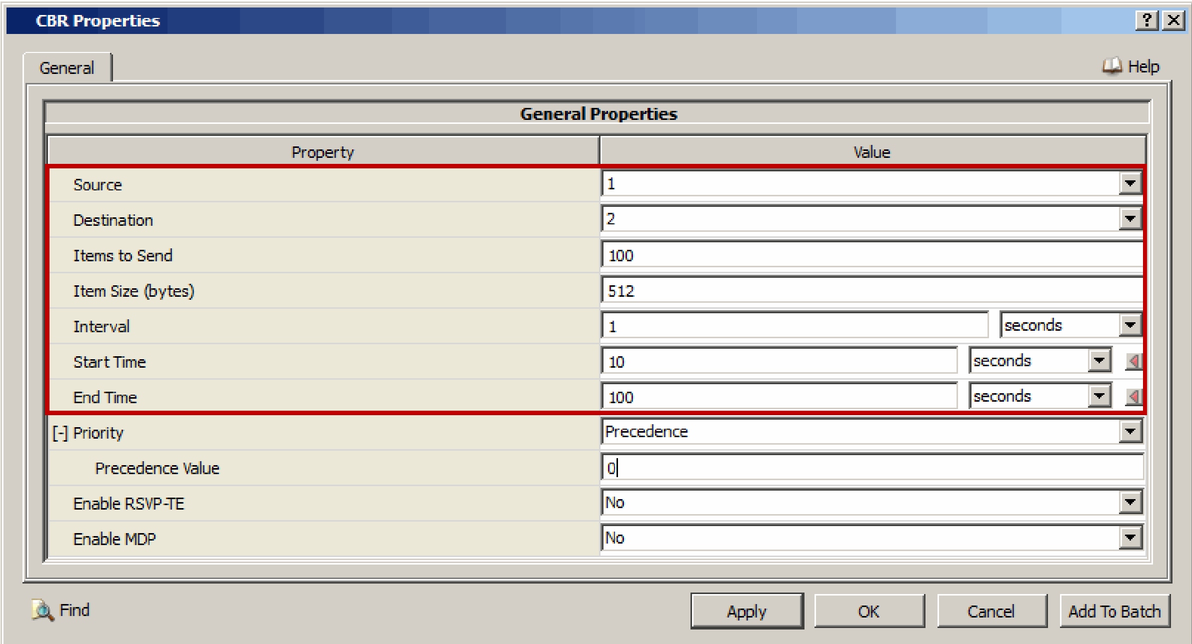


FIGURE 7-15. Sample CBR Configuration Settings

7.1.7 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the Satellite-RSV model. All scenarios are located in the directory EXATA_HOME/scenarios/satellite/rsv. Table 7-11 lists the sub-directory where each scenario is located.

TABLE 7-11. Satellite-RSV Model Scenarios

Scenario Sub-directory	Description
one-sat	Shows the example of operation of the RSV PHY.
user-defined-1	Shows the operation of the USER-DEFINED parameter of transmission mode.
multichannel	Shows the operation of the multichannel support in Satellite-RSV.

8 Mobility Models

This chapter describes features, configuration requirements and parameters, statistics, and scenarios for Mobility Models, and consists of the following sections:

- File-based Mobility Model
- Group Node Placement and Mobility Models
- Random Waypoint Mobility Model

8.1 File-based Mobility Model

8.1.1 Description

The File-based mobility model uses waypoints for each node specified by the user in a node position file. Each waypoint is a specification of a node's location and (optionally) orientation and the time at which the node arrives at that location. The node moves from one waypoint to the next in a straight line at a constant speed.

8.1.2 Command Line Configuration

To specify File-based mobility, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   MOBILITY      FILE
```

The scope of this parameter declaration can be Global or Node. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

File-based Mobility Model Parameters

Table 8-1 shows the File-based mobility model parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 8-1. File-based Mobility Model Parameters

Parameter Name	Value	Description
NODE-POSITION-FILE *Required* *Scope:* Global, Node	Filename	Specifies the name of the node position file. The same file is also used if the File-based node-placement model is used. The format of the node position file is described in Section 8.1.2.1.

8.1.2.1 Format of the Node Position File

Each line in the node position file has the following format:

```
<nodeID> <time> <position>
```

where

`<nodeID>`	Node identifier.
`<time>`	Simulation time for which the position is specified. For the initial node position, this should be 0.
`<position>`	Node position. The node position is specified as the coordinates in Cartesian or Lat-Lon-Alt system, optionally followed by the orientation (azimuth and elevation). Specifying node orientation is optional and is assumed to be (0.0 0.0) when not specified. See *EXata User's Guide* for the format for specifying node positions.

Notes:
1. For each node, the node positions should be sorted (in ascending order) by simulation time.
2. Each node position specification should be on a single line by itself.
3. Comments can be entered any where in the node position file.

Example

The following lines show a segment of a node position file:

```
1 0 (35.130587432702, -116.72249286971918, 0.0) 0 0
1 10S (35.12977099236641, -116.53095393408505, 0.0) 0.0 0.0
1 20S (35.12977099236641, -116.39738452458609, 0.0)
...
1 60S (35.36132315521628, -116.2700276457615, 0.0)
1 70S (35.465648854961835, -116.26692138042432, 0.0) 0.0 0.0
2 0 (35.16793886702846, -116.72149633406089, 0.0) 0 0
2 10S (35.16897959183674, -116.58344129312579, 0.0) 30.0 0.0
2 20S (35.16938775510204, -116.4518964383234, 0.0) 30.0 45.0
...
```

8.1.3 GUI Configuration

This section describes how to configure File-based Mobility model in the GUI. File-based Mobility model can be configured on node level only.

Configuring File-based Mobility Parameters

To configure the File-based Mobility model parameters, perform the following steps:

1. Go to **Node Properties Editor > Node Configuration > Mobility and Placement**.
2. Set **Mobility Model** to *File* and set the dependent parameters listed in Table 8-2.

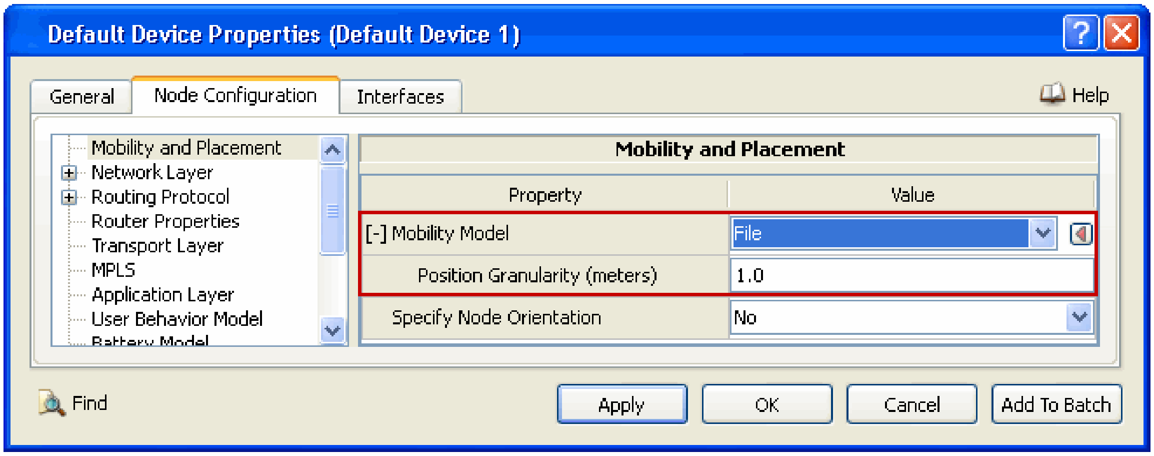


FIGURE 8-1. Setting File-based Mobility Parameters

TABLE 8-2. Command Line Equivalent of File-based Mobility Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Position Granularity	Node	`MOBILITY-POSITION-GRANULARITY`

3. Add Mobility Waypoints to the node, to define the mobility pattern of a mobile object. Refer to section 3.4.5 of the *User's Guide* for details on adding waypoints.

Note: If any waypoint to the node is added using **Mobility** button from the **Other Components** toolbar of the **Standard Toolset,** then File-based Mobility model is automatically configured on that particular node with default value of dependent parameters. These dependent parameters (listed in Table 8-2) can explicitly be configured as shown in Figure 8-1.

8.2 Group Node Placement and Mobility Models

8.2.1 Description

Group mobility model is for simulating the group movement behaviors in the real world, such as a group of travelers, etc. The members of the same group tend to have similar movement tracks. However, inside the group, members also have relative mobility. To depict such behaviors, the mobility vector of a node can be considered as the sum of two mobility vectors. One is called the group mobility vector, which is shared by all members of the same group. The other is called the internal mobility vector, which represents the relative mobility of a node inside the group. The vector sum of the two mobility vectors decides the mobility of the node. The movements of a node are also limited by the group boundary. In EXata, the two mobility vectors, group mobility vector and internal mobility vector, are simulated by using the random waypoint mobility model independently.

8.2.2 Features and Assumptions

This section describes the implemented features, omitted features, assumptions and limitations of the Group Node Placement and Mobility model.

8.2.2.1 Implemented Features

- Defining groups by specifying node IDs and configuring mobility parameters for each group in Group node placement model.
- Support for placing nodes using the following strategies: uniform, random, or grid in specified group area.
- Simulation of the group mobility.
- Flexible mobility pattern configuration which includes static groups, slow and fast moving groups, groups moving without internal mobility and with internal mobility only (in which nodes move only inside the group area as groups are static).
- Any number (not necessarily a perfect square) of nodes can be placed in a group with placement type grid.

8.2.2.2 Omitted Features

None.

8.2.2.3 Assumptions and Limitations

- If node placement method other than group node placement is used, nodes in a group should have initial positions within the group area.
- A node can only appear in one mobility group.
- Each group is one subnet. Thus, there is no explicit definition for the group member.

8.2.3 Command Line Configuration

To select the Group Node Placement model, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>] NODE-PLACEMENT   GROUP
```

To select the Group Mobility model, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>] MOBILITY   GROUP-MOBILITY
```

The scope of this parameter declaration can be Global or Node. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

Configuration Requirements

The Group Mobility model can be used only with the Group Node Placement model.

Group Node Placement and Mobility Parameters

In order to use the Group Node Placement and Group Mobility parameters, node groups have to be defined. A group definition consists of identifying the nodes that belong to the group and the area within which the nodes are placed initially.

Table 8-3 describes the Group Node Placement parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 8-3. Group Node Placement Parameters

Parameter	Value	Description
`NUM-MOBILITY-GROUPS` *Required* *Scope:* Global	Integer *Range:* `> 0`	Number of node groups.
`MOBILITY-GROUP` *Required* *Scope:* Global *Instances:* group index	Node-list	Node identifiers of the nodes in the group.
`GROUP-AREA-ORIGIN` *Required* *Scope:* Global *Instances:* group index	Coordinates	Origin of the area within which the nodes are placed initially. **Note:** The coordinates of the group area origin must be specified in the same coordinate system as is used to define the scenario terrain. If `COORDINATE-SYSTEM` is set to `CARTESIAN`, then the group area origin must be specified as a (x-coordinate, y-coordinate) pair. If `COORDINATE-SYSTEM` is set to `LATLONALT`, then the group area origin must be specified as a (latitude, longitude) pair.
`GROUP-AREA-DIMENSION` *Required* *Scope:* Global *Instances:* group index	String (see note)	Dimensions of the area within which the nodes are placed initially. **Note:** The dimensions are specified as a (x-dimension, y-dimension) pair, where the x- and y-dimensions are in meters.

TABLE 8-3. Group Node Placement Parameters (Continued)

Parameter	Value	Description
`GROUP-NODE-PLACEMENT` *Required* *Scope:* Global *Instances:* group index	List: • `RANDOM` • `UNIFORM` • `GRID`	Node placement model used for the initial placement of nodes with the group area. Refer to *Developer Model Library* for a description of these node placement models and the additional parameters that need to be specified for each placement model.
`GROUP-SEED` *Optional* *Scope:* Global, Integer	Integer *Range:* ≥ `0` *Default:* (see note)	Used to generate random number streams for a specific group. **Note:** The default value of `GROUP-SEED` is the value of the `SEED` parameter. Refer to *EXata User's Guide* for a description of the `SEED` parameter.
`GROUP-GRID-UNIT` *Optional* *Scope:* Global	Real *Range:* > `0` *Default:* (see note) *Unit:* meters (in Cartesian), degrees (in Lat-Lon-Alt)	Specifies the distance between the nodes of a specific group when they are placed in a grid format. **Note:** The default value of `GROUP-GRID-UNIT` is the value of the `GRID-UNIT` parameter used by the Grid Node Placement Model (refer to *Developer Model Library*).

Table 8-4 describes the Group Mobility parameters.

TABLE 8-4. Group Mobility Parameters

Parameter	Value	Description
`MOBILITY-GROUP-PAUSE` *Optional* *Scope:* Global *Instances:* group index	Time	Pause interval for the group.
`MOBILITY-GROUP-MIN-SPEED` *Optional* *Scope:* Global *Instances:* group index	Real *Unit:* meters/sec	Minimum speed of the group.
`MOBILITY-GROUP-MAX-SPEED` *Optional* *Scope:* Global *Instances:* group index	Real *Unit:* meters/sec	Maximum speed of the group.

TABLE 8-4. Group Mobility Parameters (Continued)

Parameter	Value	Description
`MOBILITY-GROUP-INTERNAL-PAUSE` *Optional* *Scope:* Global *Instances:* group index	Time	Pause interval for individual nodes within the group.
`MOBILITY-GROUP-INTERNAL-MIN-SPEED` *Optional* *Scope:* Global *Instances:* group index	Real *Unit:* meters/sec	Minimum speed of individual nodes within the group.
`MOBILITY-GROUP-INTERNAL-MAX-SPEED` *Optional* *Scope:* Global *Instances:* group index	Real *Unit:* meters/sec	Maximum speed of individual nodes within the group.
`GROUP-TERRAIN-CONSTRAINT-SOUTH-WEST-CORNER` *Optional* (see note 1) *Scope:* Global *Instances:* group index	Coordinates	South-west corner of the region within which the group is constrained to move. **Note:** The south-west corner of the region should lie within the terrain area specified for the scenario.
`GROUP-TERRAIN-CONSTRAINT-NORTH-EAST-CORNER` *Optional* (see note 1) *Scope:* Global *Instances:* group index	Coordinates	North-east corner of the region within which the group is constrained to move. **Note:** The north-east corner of the region should lie within the terrain area specified for the scenario.

TABLE 8-4. Group Mobility Parameters (Continued)

Parameter	Value	Description
GROUP-TERRAIN-CONSTRAINT-LOWER-LEFT-CORNER *Optional* (see note 2) *Scope:* Global *Instances:* group index	Coordinates	Lower left corner of the region within which the group is constrained to move. **Note:** The lower left corner of the region should lie within the terrain area specified for the scenario.
GROUP-TERRAIN-CONSTRAINT-UPPER-RIGHT-CORNER *Optional* (see note 2) *Scope:* Global *Instances:* group index	Coordinates	Upper right corner of the region within which the group is constrained to move. **Note:** The upper right corner of the region should lie within the terrain area specified for the scenario.

Notes: 1. Parameters GROUP-TERRAIN-CONSTRAINT-SOUTH-WEST-CORNER and GROUP-TERRAIN-CONSTRAINT-NORTH-EAST-CORNER are applicable only if the Lat-Lon-Alt coordinate system is used and is specified as a (latitude, longitude) pair. If the Lat-Lon-Alt coordinate system is used and these parameters are not specified, then the group can move over the entire terrain of the scenario.

2. Parameters GROUP-TERRAIN-CONSTRAINT-LOWER-LEFT-CORNER and GROUP-TERRAIN-CONSTRAINT-UPPER-RIGHT-CORNER are applicable only if the Cartesian coordinate system is used and is specified as a (x-coordinate, y-coordinate) pair. If these parameters are not specified, then the group can move over the entire terrain of the scenario.

8.2.4 GUI Configuration

The Group Mobility model can not be configured using the GUI.

8.2.5 Sample Scenario

8.2.5.1 Scenario Description

The sample scenario demonstrates the above group mobility parameters. In this scenario, a total of five groups are defined. They are:

- Group 0: From node 1 to node 40. This group is static, with nodes scattered in the whole simulation field.
- Group 1: From node 41 to node 50. This is a fast moving group with speed between 40 m/s to 60 m/s.
- Group 2: From node 51 to node 60. This is a fast moving group with speed between 20 m/s to 40 m/s.
- Group 3: From node 61 to node 70. This is a middle-speed moving group with speed between 10 m/s to 20 m/s.
- Group 4: From node 71 to node 80. This is a slow-moving group with speed between 1 m/s to 10 m/s.

8.2.5.2 Command Line Configuration

To configure the above mobility scenario, use the following parameters:

```
# A total of 80 nodes in the scenario
SUBNET N16-0 {1 thru 80}

# Define groups
NUM-MOBILITY-GROUPS    5
MOBILITY-GROUP[0] {1 thru 40}
MOBILITY-GROUP[1] {41 thru 50}
MOBILITY-GROUP[2] {51 thru 60}
MOBILITY-GROUP[3] {61 thru 70}
MOBILITY-GROUP[4] {71 thru 80}

# Define initial group areas
GROUP-AREA-ORIGIN[0]    (0, 0)
GROUP-AREA-DIMENSION[0] (1500, 1500)
GROUP-AREA-ORIGIN[1]    (150, 150)
GROUP-AREA-DIMENSION[1] (450, 450)
GROUP-AREA-ORIGIN[2]    (900, 150)
GROUP-AREA-DIMENSION[2] (450, 450)
GROUP-AREA-ORIGIN[3]    (150, 900)
GROUP-AREA-DIMENSION[3] (450, 450)
GROUP-AREA-ORIGIN[4]    (900, 900)
GROUP-AREA-DIMENSION[4] (450, 450)

GROUP-NODE-PLACEMENT[0]  UNIFORM
GROUP-NODE-PLACEMENT[1]  UNIFORM
GROUP-NODE-PLACEMENT[2]  UNIFORM
GROUP-NODE-PLACEMENT[3]  UNIFORM
GROUP-NODE-PLACEMENT[4]  UNIFORM

# Specify group node placement
NODE-PLACEMENT   GROUP

# Specify group mobility model and configure movement speeds
MOBILITY    GROUP-MOBILITY

# Group 0 is static
MOBILITY-GROUP-PAUSE[0]                0S
MOBILITY-GROUP-MIN-SPEED[0]            0
MOBILITY-GROUP-MAX-SPEED[0]            0
MOBILITY-GROUP-INTERNAL-PAUSE[0]       0S
MOBILITY-GROUP-INTERNAL-MIN-SPEED[0]   0
MOBILITY-GROUP-INTERNAL-MAX-SPEED[0]   0

# Group 1 is a fast moving group with speed between 40 m/s to 60 m/s
MOBILITY-GROUP-PAUSE[1]                0S
MOBILITY-GROUP-MIN-SPEED[1]            40
MOBILITY-GROUP-MAX-SPEED[1]            60
MOBILITY-GROUP-INTERNAL-PAUSE[1]       10S
MOBILITY-GROUP-INTERNAL-MIN-SPEED[1]   10
MOBILITY-GROUP-INTERNAL-MAX-SPEED[1]   20
```

```
# Group 2 is a fast moving group with speed between 20 m/s to 40 m/s
MOBILITY-GROUP-PAUSE[2]                 0S
MOBILITY-GROUP-MIN-SPEED[2]             20
MOBILITY-GROUP-MAX-SPEED[2]             40
MOBILITY-GROUP-INTERNAL-PAUSE[2]        10S
MOBILITY-GROUP-INTERNAL-MIN-SPEED[2]    10
MOBILITY-GROUP-INTERNAL-MAX-SPEED[2]    20

# Group 3 is a middle speed moving group with speed between
# 10 m/s to 20 m/s
MOBILITY-GROUP-PAUSE[3]                 10S
MOBILITY-GROUP-MIN-SPEED[3]             10
MOBILITY-GROUP-MAX-SPEED[3]             20
MOBILITY-GROUP-INTERNAL-PAUSE[3]        10S
MOBILITY-GROUP-INTERNAL-MIN-SPEED[3]    10
MOBILITY-GROUP-INTERNAL-MAX-SPEED[3]    20

# group 4 is a slow moving group with speed between 1m/s to 10m/s
MOBILITY-GROUP-PAUSE[4]                 10S
MOBILITY-GROUP-MIN-SPEED[4]             1
MOBILITY-GROUP-MAX-SPEED[4]             10
MOBILITY-GROUP-INTERNAL-PAUSE[4]        10S
MOBILITY-GROUP-INTERNAL-MIN-SPEED[4]    10
MOBILITY-GROUP-INTERNAL-MAX-SPEED[4]    20
```

8.2.6 Scenarios Included in EXata

EXata distribution includes several sample scenarios for the Group Node Placement and Mobility models. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/group-mobility. Table 8-5 lists the sub-directory where each scenario is located.

TABLE 8-5. Group Node Placement and Mobility Scenarios Included in EXata

Scenario	Description
5groups	Shows the Group Mobility model.

8.2.7 References

1. X. Hong, M. Gerla, G. Pei and C.-C. Chiang. "A Group Mobility Model for Ad Hoc Wireless Networks." ACM/IEEE MSWiM'99, Seattle, WA. August 1999.

8.3 Random Waypoint Mobility Model

8.3.1 Description

The Random Waypoint mobility model selects random destinations and speeds for each node. After the nodes reach their selected destinations, they pause for a given amount of time and then the process is repeated.

8.3.2 Command Line Configuration

To specify Random Waypoint mobility, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]  MOBILITY      RANDOM-WAYPOINT
```

The scope of this parameter declaration can be Global or Node. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

Random Waypoint Mobility Parameters

Table 8-6 describes the Random Waypoint mobility configuration parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 8-6. Random Waypoint Mobility Parameters

Parameter name	Value	Description
`MOBILITY-WP-PAUSE` *Required* *Scope:* Global, Node	Time *Range:* ≥ `0S`	This parameter is used to specify the delay while the node is mobile.
`MOBILITY-WP-MIN-SPEED` *Required* *Scope:* Global, Node	Real *Range:* `> 0` *Unit:* meters/sec	This parameter is used to specify minimum waypoint speed.
`MOBILITY-WP-MAX-SPEED` *Required* *Scope:* Global, Node	Real *Range:* `> 0` *Unit:* meters/sec	This parameter is used to specify maximum waypoint speed.

8.3.3 GUI Configuration

This section describes how to configure Random Waypoint Mobility model in the GUI.

Configuring Random Waypoint Mobility Parameters

Random Waypoint mobility parameters are specified at the node level.

To configure the Random Waypoint Mobility model, perform the following steps:

1. Go to **Node Properties Editor > Node Configuration > Mobility and Placement**.
2. Set **Mobility Model** to *Random Waypoint* and set the dependent parameters listed in Table 8-7.

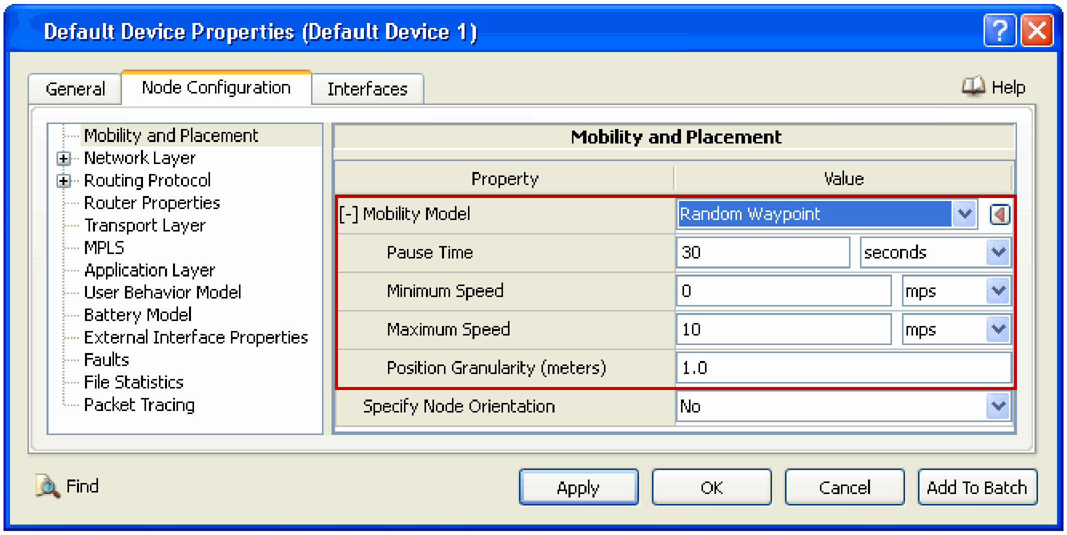


FIGURE 8-2. Setting Random Waypoint Mobility Parameters

TABLE 8-7. Command Line Equivalent of Random Waypoint Mobility Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Pause Time	Node	`MOBILITY-WP-PAUSE`
Minimum Speed	Node	`MOBILITY-WP-MIN-SPEED`
Maximum Speed	Node	`MOBILITY-WP-MAX-SPEED`
Position Granularity	Node	`MOBILITY-POSITION-GRANULARITY`

9 Terrain Models

This chapter describes features, configuration requirements and parameters, statistics, and scenarios for Terrain Models, and consists of the following sections:

- Cartesian Terrain Format
- Digital Elevation Model (DEM) Terrain Format
- Digital Terrain Elevation (DTED) Terrain Format
- ESRI Shapefile Terrain Format
- Urban Terrain Data Format

9.1 Cartesian Terrain Format

9.1.1 Description

EXata's Cartesian terrain format is intended to provide terrain data for small areas specified in Cartesian coordinates.

9.1.2 Command Line Configuration

To specify Cartesian as the terrain format, include the following parameter in the scenario configuration (.config) file:

```
TERRAIN-DATA-TYPE      CARTESIAN
```

Configuration Requirements

In order to use the Cartesian terrain format, the coordinate system must be configured to be Cartesian.

Cartesian Terrain Parameters

Table 9-1 shows the Cartesian terrain parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 9-1. Cartesian Terrain Parameters

Parameter Name	Value	Description
`CARTESIAN-FILENAME` Required *Scope:* Global	Filename	Name of the file that contains Cartesian terrain data. The format of this file is described in Section 9.1.2.1.
`TERRAIN-DATA-BOUNDARY-CHECK` Optional *Scope:* Global	List: • `YES` • `NO` *Default:* `YES`	Indication whether a check should be made to see if, during the simulation, a node's position is within the range covered by the terrain data. `YES` : If a node moves to a location for which there is no terrain data, the simulation terminates. `NO` : If a node moves to a location for which there is no terrain data, the simulation continues by assuming that the elevation at that location is 0.0 meters.

9.1.2.1 Format of the Cartesian Terrain Data File

The Cartesian terrain data file is essentially an X by Y grid of elevations, specified in meters.

The first line in the Cartesian data file has the following format:

```
<Num-X-data-points> <Num-Y-data-points> <Spacing>
```

where

`<Num-X-data-points>`	Number of data points in the X direction.
`<Num-Y-data-points>`	Number of data points in the Y direction.
`<Spacing>`	Spacing between data points, in meters.

The first line is followed by `<Num-Y-data-points>` lines, one for each Y-value. Each line has `<Num-X-data-points>` entries, one for each X-value, and indicates the elevation (in meters) at that position.

Note: The lines in the file are in increasing order of Y-value and entries on a line are in increasing order of X-value. Thus, the first entry on the second line of the file is the elevation at the origin and the last entry on the last line is the elevation at the upper-right corner of the terrain (or the location closest to it that can be specified with the chosen spacing).

Example

The following is an example of a Cartesian terrain data file:

```
3 3 1
0.00 0.00 0.00
0.00 0.50 0.00
0.00 0.00 0.00
```

This Cartesian terrain data file specifies a 3 by 3 grid with 1 meter spacing between data points. It also indicates an elevation of 0.50 meters at data point(1,1) in the grid.

9.1.3 GUI Configuration

This section describes how to configure terrain data in DEM format in the GUI.

Configuration Requirements

In order to use the Cartesian terrain format, the coordinate system must be configured to be Cartesian.

Configuring DEM Terrain Parameters

To configure the Cartesian terrain parameters in the GUI perform the following steps:

1. Go to the **Scenario Properties Editor > Terrain**.
2. Set the **Terrain Data Format** to *Cartesian* and set the dependent parameters listed in Table 9-2.

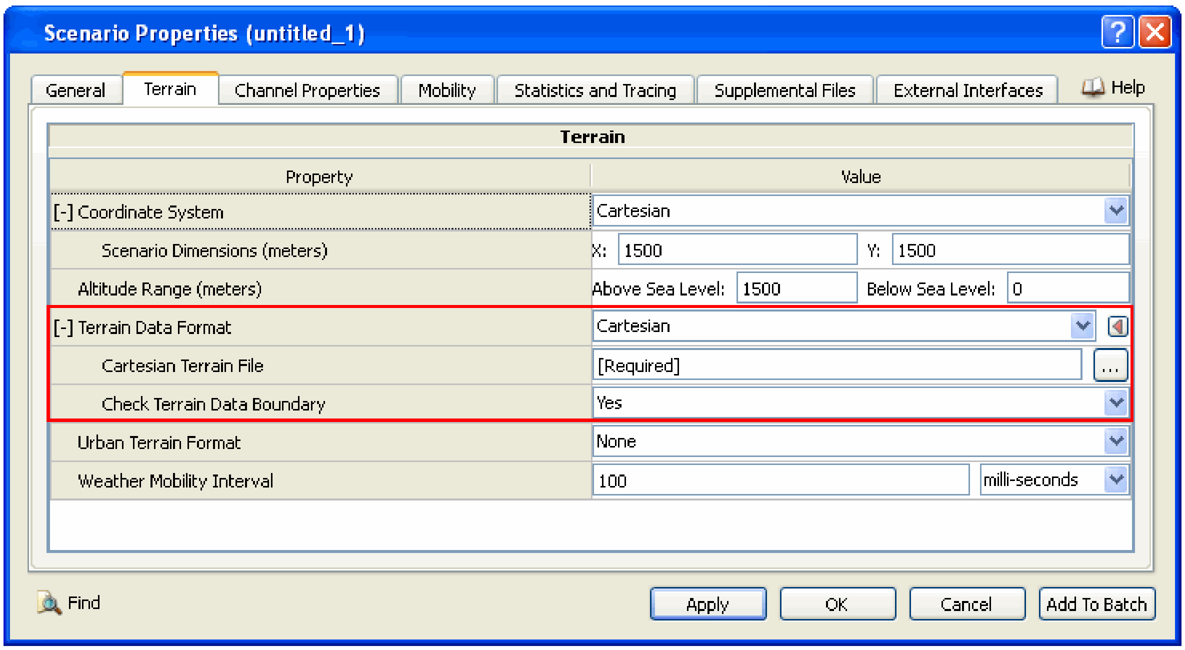


FIGURE 9-1. Setting Cartesian Terrain Parameters

TABLE 9-2. Command Line Equivalent of Cartesian Terrain Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Cartesian Terrain File	Global	`CARTESIAN-FILENAME`
Check Terrain Data Boundary	Global	`TERRAIN-DATA-BOUNDARY-CHECK`

Setting Parameters

- Set **Cartesian Terrain File** to the name of the Cartesian Terrain File. The format of the Cartesian Terrain File is described in Section 9.1.2.1.

9.1.4 Statistics

There are no statistics collected for the Cartesian terrain model.

9.1.5 References

None.

9.2 Digital Elevation Model (DEM) Terrain Format

9.2.1 Description

Digital Elevation Model (DEM) is a standard format for representing terrain elevation data. It is a digital representation of ground surface topography or terrain format.

DEM files are produced by the USGS. EXata supports only 1 degree files with elevation points in a grid of approximately 100 meters spacing.

9.2.2 Command Line Configuration

To specify DEM as the terrain format, include the following parameter in the scenario configuration (.config) file:

```
TERRAIN-DATA-TYPE       DEM
```

Configuration Requirements

In order to use the DEM terrain format, the coordinate system must be configured to be Latitude-Longitude-Altitude.

DEM Terrain Parameters

Table 9-3 shows the DEM terrain parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 9-3. DEM Terrain Parameters

Parameter	Value	Description
`DEM-FILENAME` Required *Scope:* Global *Instances:* file index	Filename	Specifies the relative or absolute path and filename for the DEM data file for the selected terrain. Include as many instances of this parameter as the number of DEM files. If there is only one DEM file, the index can be omitted. The relative path is relative to EXATA_HOME.
`TERRAIN-DATA-BOUNDARY-CHECK` Optional *Scope:* Global	List: • `YES` • `NO` *Default:* `YES`	Indication whether a check should be made to see if, during the simulation, a node's position is within the range covered by the terrain data. `YES` : If a node moves to a location for which there is no terrain data, the simulation terminates. `NO` : If a node moves to a location for which there is no terrain data, the simulation continues by assuming that the elevation at that location is 0.0 meters.

9.2.3 GUI Configuration

This section describes how to configure terrain data in DEM format in the GUI.

Configuration Requirements

In order to use the DEM terrain format, the coordinate system must be configured to be Latitude-Longitude-Altitude.

Configuring DEM Terrain Parameters

To configure the DEM terrain parameters perform the following steps:

1. Go to the **Scenario Properties Editor > Terrain**.
2. Set **Coordinate System** to *Latitude-Longitude*.
3. Set **Terrain Data Format** to *USGS DEM* and set the dependent parameters listed in Table 9-4.

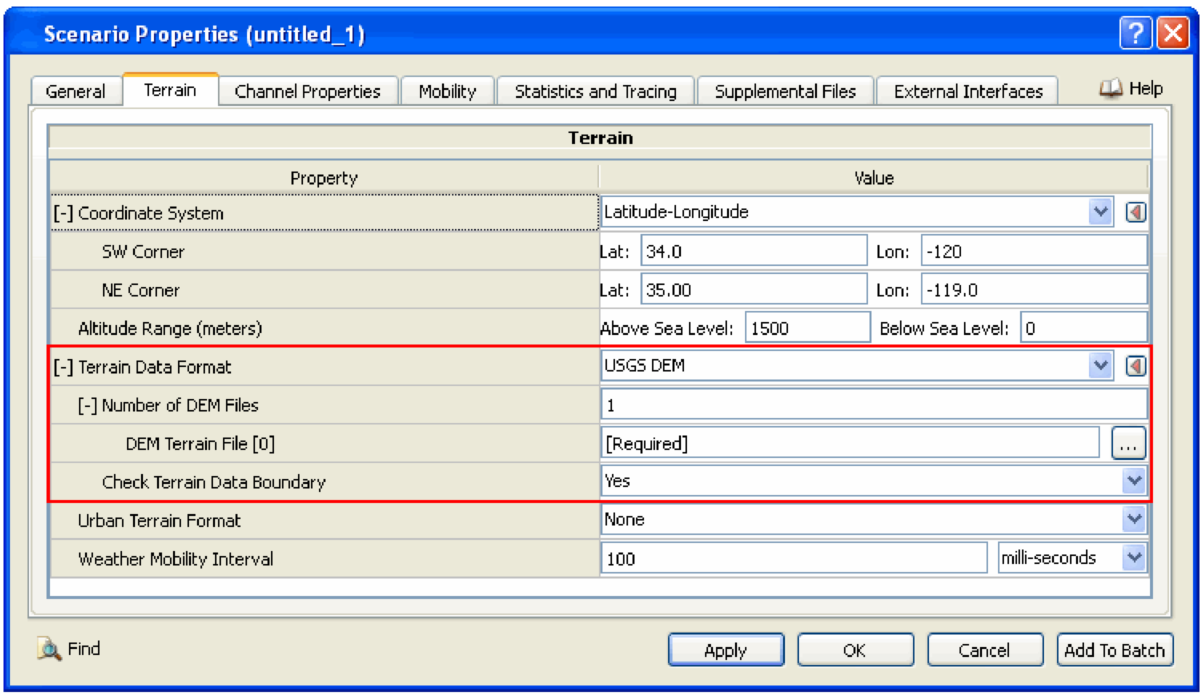


FIGURE 9-2. Setting DEM Terrain Parameters

TABLE 9-4. Command Line Equivalent of DEM TErrain Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Number of DEM Files	Global	`N/A`
DEM Terrain File [*i*]	Global	`DEM-FILENAME[i]`
Check Terrain Data Boundary	Global	`TERRAIN-DATA-BOUNDARY-CHECK`

Setting Parameters

- Set **Number of DEM Files** to the number of DEM terrain files used in the scenario.
- Set **DEM Terrain File[i]** to the name of the i^{th} DEM Terrain File.

9.2.4 Statistics

There are no statistics collected for the DEM terrain model.

9.2.5 Scenarios Included in QualNet

The EXata distribution includes several sample scenarios for the DEM Terrain model. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/terrain-dem. Table 9-5 lists the sub-directory where each scenario is located.

TABLE 9-5. DEM Terrain Scenarios Included in EXata

Scenario	Description
HighSpeedMobility	Shows the use of DEM terrain files.

9.2.6 References

1. The government standard is available at:

"Digital Elevation Model Standards." U.S. Geological Survey. 1998. http://rockyweb.cr.usgs.gov/nmpstds/demstds.html

2. Data Sets Information is available at:

"USGS Geographic Data Download.". U.S. Geological Survey. http://edc2.usgs.gov/geodata/index.php

3. Legacy/"native" format 1x1 degree information is available at:

U.S. Geological Survey. http://edcftp.cr.usgs.gov/pub/data/DEM/250/.

9.3 Digital Terrain Elevation (DTED) Terrain Format

9.3.1 Description

Digital Terrain Elevation Data (DTED) is a format for representing terrain elevation data. DTED files provide basic quantitative data for systems and application that require terrain elevation, slope, and surface roughness information.

DTED data are available from a variety of sources and in various resolutions. All resolutions contain grids of elevation points. DTED level 0 is spaced at about 1000 meters per data point, DTED level 1 at 100 meters, DTED level 2 at 30 meters, DTED level 3 at 10 meters, DTED level 4 at 3 meters, and DTED level 5 at 1 meter.

EXata supports use of multi-resolution DTED files (levels 0, 1 and 2).

9.3.2 Assumptions and Limitations

The maximum number of DTED files that can be loaded simultaneously in a scenario is 100.

Note: This number can be modified if needed. Contact support@scalable-networks.com for more information.

9.3.3 Supplemental Information

The memory consumption of DTED terrain files depends on the type of file used and on the size of the file.

- DTED Level 0 files use about 25-50 KB.
- DTED Level 1 files use about 2.5-3.5 MB.

In a cluster environment every processor loads every DTED file in the simulation. So if a scenario uses 100 DTED Level 1 files of size 2.8 MB each and the scenario is run on a 16 processor cluster, the memory used will be 280 MB per processor, or about 4.5 GB total.

9.3.4 Command Line Configuration

To specify DTED as the terrain format, include the following parameter in the scenario configuration (.config) file:

```
TERRAIN-DATA-TYPE        DTED
```

Configuration Requirements

In order to use the DTED terrain format, the coordinate system must be configured to be Latitude-Longitude-Altitude.

DTED Terrain Parameters

Table 9-6 lists the DTED terrain parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 9-6. DTED Terrain Parameters

Parameter	Value	Description
`DTED-FILENAME` Required *Scope:* Global *Instances:* file index	Filename	Specifies the relative or absolute path and filename for the DTED data file for the selected terrain. Include as many instances of this parameter as the number of DTED files. If there is only one DTED file, the index can be omitted. The path is relative to EXATA_HOME.
`TERRAIN-DATA-BOUNDARY-CHECK` *Optional* *Scope:* Global	List: • `YES` • `NO` *Default:* `YES`	Indication whether a check should be made to see if, during the simulation, a node's position is within the range covered by the terrain data. `YES` : If a node moves to a location for which there is no terrain data, the simulation terminates. `NO` : If a node moves to a location for which there is no terrain data, the simulation continues by assuming that the elevation at that location is 0.0 meters.

9.3.5 GUI Configuration

This section describes how to configure terrain data in DTED format in the GUI.

Configuration Requirements

In order to use the DTED terrain format, the coordinate system must be configured to be Latitude-Longitude-Altitude.

Configuring DTED Terrain Parameters

To configure the DTED terrain data parameters perform the following steps:

1. Go to the **Scenario Properties Editor > Terrain**.
2. Set **Coordinate System** *to Latitude-Longitude.*
3. *Set* **Terrain Data Format** to *DTED* and set the parameters listed in Table 9-7.

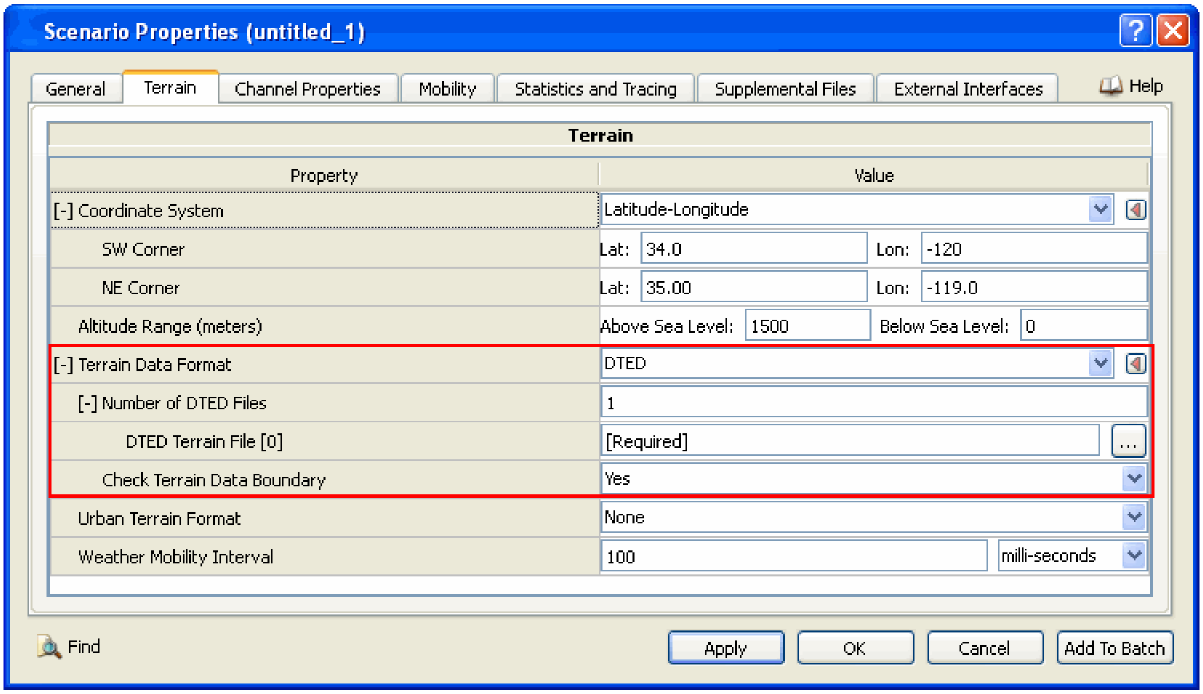


FIGURE 9-3. Setting DTED Terrain Parameters

TABLE 9-7. Command Line Equivalent of DTED Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Number of DTED Files	Global	`N/A`
DTED Terrain File [*i*]	Global	`DTED-FILENAME[i]`
Check Terrain Data Boundary	Global	`TERRAIN-DATA-BOUNDARY-CHECK`

Setting Parameters

- Set **Number of DTED Files** to the number of DTED terrain files used in the scenario.
- Set **DTED Terrain File[i]** to the name of the i^{th} DTED terrain file.

9.3.6 Statistics

There are no statistics collected for the DTED terrain format.

9.3.7 Scenarios Included in QualNet

The EXata distribution includes several sample scenarios for the DTED Terrain model. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/terrain-dted. Table 9-8 lists the sub-directory where each scenario is located.

TABLE 9-8. DTED Terrain Scenarios Included in EXata

Scenario	Description
dtedtest	Demonstrate QualNet's support for DTED terrain files.

9.3.8 References

None.

9.4 ESRI Shapefile Terrain Format

9.4.1 Description

ESRI shapefiles are a popular means of describing geospatial data. EXata supports extracting building and foliage area outlines from ESRI shapefiles and converting these into QualNet Terrain Format (see Section 9.5).

A shapefile actually consists of a collection of files of the following types which are described below:

- Main files (with file extension .shp)
- Index files (with file extension .shx)
- dBASE files (with file extension .dbf)

The shapefiles used by the EXata Shapefile model are described below.

Main Files

- Each file defines a collection of 2D polygons defining 2D buildings and 2D foliage footprints.
- Each point describing the footprint is represented by a pair of real numbers: the first number is the longitude (in degrees) and the second number is the latitude (in degrees). (Negative values represent latitude west and longitude south, respectively).
- Each stores only terrain features of the same type (i.e., there can be one or more terrain files storing only buildings, one or more terrain files storing only foliage, etc.).
- If shapefiles are used in conjunction with other terrain data files, the buildings in the .shp files should be geo-referenced using the same coordinate system as the other terrain data files, such as DTED/ WGS84.

Index Files

- Although it can be derived from the main (.shp) file, the index file must be present since it is required by the shapelib open-source library used by EXata.
- An index file lists the offsets for each record in the main (.shp) file.

dBASE Files

- The dBASE files use a version of the dBASE database format, in which there are a set of user-defined fields which cover the entire database (every record in the database may have a value for each field).
- There is exactly one record for every shape in the main (.shp) file. The order of records is the same as the order of shapes in the main file.
- Each field name consists of 11 bytes of useful character data plus 1 byte for a null terminator.
- A dBASE file may contain the following types of information:
  - Height of the terrain feature above the ground (not the absolute height above the reference ellipsoid or geoid).
  - Units to be used for the height and other parameters.
  - Other parameters of the terrain feature, such as foliage density, etc.

Note: Default values for terrain parameters (e.g., default building/foliage type, default height, default height units, etc.) can be specified in the EXata scenario configuration (.config) file (see Section 9.4.4) or in the dBASE file. Values specified in the scenario configuration file take precedence over the values specified in the dBASE file.

9.4.2 Assumptions and Limitations

Although ESRI shapefiles have a very generic format, the EXata Shapefile model supports only files conforming to the format described in Section 9.4.1.

9.4.3 Using ESRI Shapefiles

There are two ways to use ESRI shapefiles for terrain features data:

- Convert the ESRI shapefiles into equivalent QualNet Terrain Format files using the using the Shapefile-to-XML utility program (refer to *EXata User's Guide* for details of this utility program). Use these QualNet Terrain Format files as the terrain features data source, as described in Section 9.5.
- Specify ESRI shapefiles and the associated parameters directly in the scenario configuration file, as described in Section 9.4.4 and Section 9.4.5.

9.4.4 Command Line Configuration

To use ESRI Shapefile format for terrain features data, include the following parameters in the scenario configuration (.config) file:

```
URBAN-TERRAIN-TYPE          QUALNET-URBAN-TERRAIN
TERRAIN-FEATURES-SOURCE     SHAPEFILE
```

ESRI Shapefile Terrain Parameters

Table 9-9 lists the ESRI Shapefile terrain parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 9-9. ESRI Shapefile Terrain Parameters

Parameter	Value	Description
SHAPEFILE-PATH *Required* *Scope:* Global *Instances:* file indexfile index	Path	Path to the shapefile. By convention, this points to the .shp file. Associated files such as .shx and .dbf must have the same primary file name and exist in the same folder.

TABLE 9-9. ESRI Shapefile Terrain Parameters (Continued)

Parameter	Value	Description
SHAPEFILE-DEFAULT-SHAPE-TYPE *Optional* *Scope:* Global *Instances:* file index	List: • BUILDING • FOLIAGE *Default:* BUILDING	Type of object represented in the shapefile. Each shapefile can only represent one type of object.
SHAPEFILE-DEFAULT-MSMT-UNIT *Optional* *Scope:* Global *Instances:* file index	List: • METERS • FEET *Default:* FEET	Default unit for specifying the height of objects in the shapefile.
SHAPEFILE-DEFAULT-BLDG-HEIGHT *Optional* *Scope:* Global *Instances:* file index	Integer *Range:* > 0 *Default:* 35	Default height for buildings in the shapefile. This can be used in lieu of specifying individual building heights in the shapefile, but makes all buildings the same height.
SHAPEFILE-DEFAULT-FOLIAGE-HEIGHT *Optional* *Scope:* Global *Instances:* file index	Integer *Range:* > 0 *Default:* 35	Default height for foliage in the shapefile. This can be used in lieu of specifying individual foliage heights in the shapefile, but makes all foliage the same height.
SHAPEFILE-DEFAULT-FOLIAGE-DENSITY *Optional* *Scope:* Global *Instances:* file index	Real *Range:* [0.0, 1.0] *Default:* 0.15	Default foliage density. Foliage is represented as an area, like a park or forest, that has trees. This variable defines how much of the area is covered by trees.
SHAPEFILE-DBF-FILE-MSMT-UNIT *Optional* *Scope:* Global *Instances:* file index	List: • METERS • FEET *Default:* FEET	Units for height values in the .dbf file. This parameter is used when individual building/ foliage heights are specified in the .dbf file rather than globally in the configuration file.

TABLE 9-9. ESRI Shapefile Terrain Parameters (Continued)

Parameter	Value	Description
`SHAPEFILE-DBF-BLDG-HEIGHT-TAG-NAME` *Optional* *Scope:* Global *Instances:* file index	String *Default:* `LV`	Tag name for building height property in the .dbf file. This parameter is used when individual building heights are specified in the .dbf file rather than globally in the configuration file.
`SHAPEFILE-DBF-FOLIAGE-HEIGHT-TAG-NAME` *Optional* *Scope:* Global *Instances:* file index	String *Default:* `LV`	Tag name for foliage height property in the .dbf file. This parameter is used when individual foliage heights are specified in the .dbf file rather than globally in the configuration file.
`SHAPEFILE-DBF-FOLIAGE-DENSITY-TAG-NAME` *Optional* *Scope:* Global *Instances:* file index	String *Default:* `DENSITY`	Tag name for foliage density property in the .dbf file. This parameter is used when individual foliage densities are specified in the .dbf file rather than globally in the configuration file.
`FOLIAGE-FOLIATED-STATE` *Required* *Scope:* Global	List: • `IN-LEAF` • `OUT-OF-LEAF`	This variable is applied to the propagation model as signals pass through the foliage.
`TERRAIN-FEATURES-SET-TO-GROUND` *Required* *Scope: Global*	List: • `YES` • `NO`	Specifies whether the simulator should use the ground elevation from the terrain file rather than the elevation from the shapefile.

9.4.5 GUI Configuration

To configure the ESRI Shapefile parameters in the GUI, perform the following steps:

1. Go to **Scenario Properties Editor > Terrain**.
2. Set **Urban Terrain Features Format** to *QualNet Format*, and **Urban Terrain Features Format** to *Shapefile*.
3. Set the dependent parameters listed in Table 9-10.

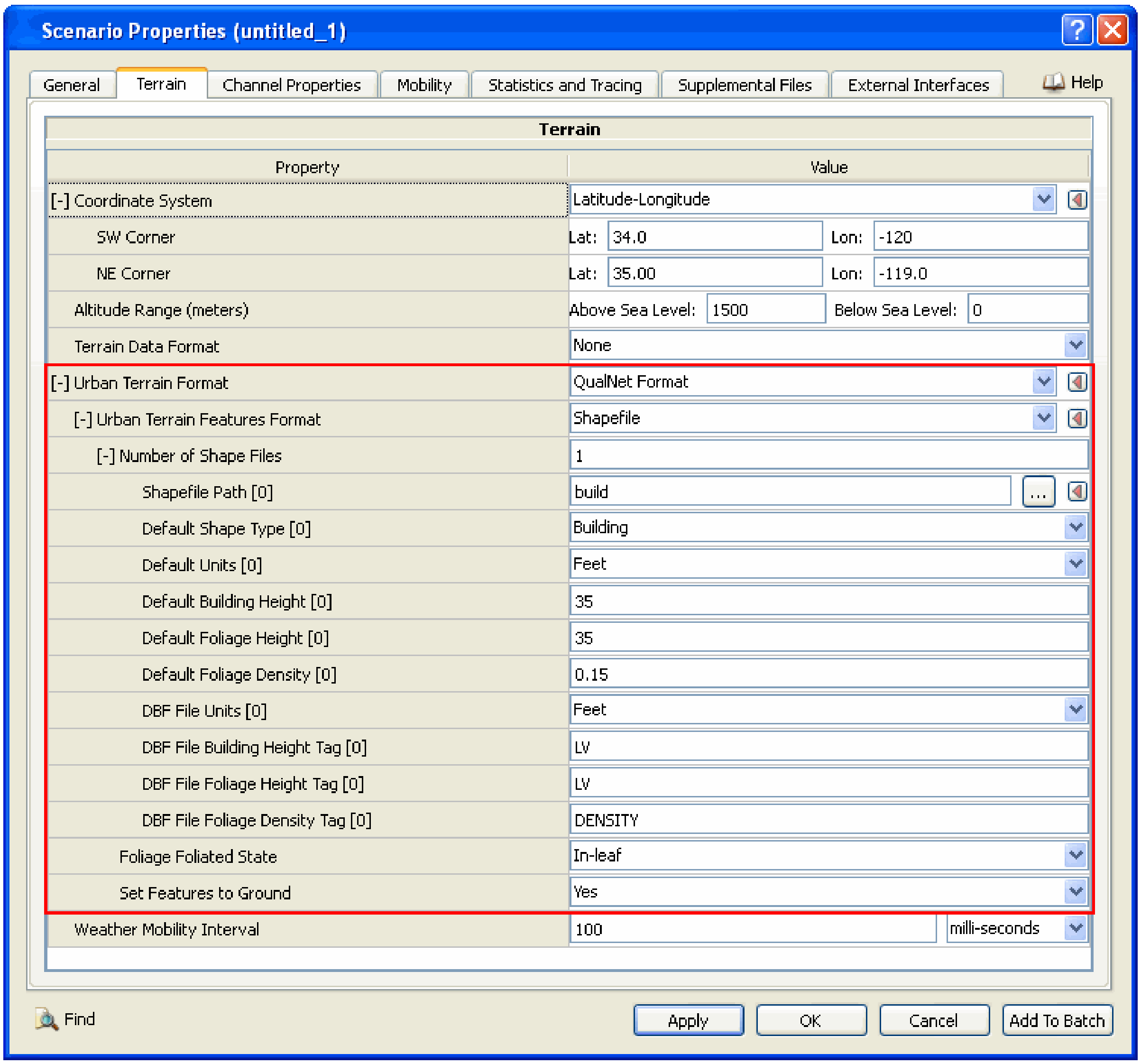


FIGURE 9-4. Setting ESRI Shapefile Terrain Parameters

TABLE 9-10. Command Line Equivalent of ESRI Shapefile Terrain Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Shapefile Path [*i*]	Global	`SHAPEFILE-PATH[i]`
Default Shape Type [*i*]	Global	`SHAPEFILE-DEFAULT-SHAPE-TYPE[i]`
Default Units [*i*]	Global	`SHAPEFILE-DEFAULT-MSMT-UNIT[i]`
Default Building Height [*i*]	Global	`SHAPEFILE-DEFAULT-BLDG-HEIGHT[i]`
Default Foliage Height [*i*]	Global	`SHAPEFILE-DEFAULT-FOLIAGE-HEIGHT[i]`
Default Foliage Density [*i*]	Global	`SHAPEFILE-DEFAULT-FOLIAGE-DENSITY[i]`
DBF File Units [*i*]	Global	`SHAPEFILE-DBF-FILE-MSMT-UNIT[i]`
DBF File Building Height Tag [*i*]	Global	`SHAPEFILE-DBF-BLDG-HEIGHT-TAG-NAME[i]`
DBF File Foliage Height Tag [*i*]	Global	`SHAPEFILE-DBF-FOLIAGE-HEIGHT-TAG-NAME[i]`
DBF File Foliage Density Tag [*i*]	Global	`SHAPEFILE-DBF-FOLIAGE-DENSITY-TAG-NAME[i]`
Foliage Foliated State	Global	`FOLIAGE-FOLIATED-STATE`
Set Features to Ground	Global	`TERRAIN-FEATURES-SET-TO-GROUND`

9.4.6 Statistics

There are no statistics collected for the ESRI Shapefile model.

9.4.7 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the ESRI Shapefile model. All scenarios are located in the directory EXATA_HOME/scenarios/urban. Table 9-11 lists the sub-directory where each scenario is located.

TABLE 9-11. ESRI Shapefile Scenarios Included in EXata

Scenario	Description
shapefile	Illustrates the use of ESRI shapefiles.

9.4.8 References

None.

9.5 Urban Terrain Data Format

9.5.1 Description

The features of the terrain, such as ground elevation at different points and the dimensions of buildings, affect the strength of signals transmitted by nodes. To accurately model the extent of signal attenuation, EXata takes the terrain features into account.

QualNet Terrain Format is a proprietary XML format provided by Scalable Network Technologies that allows users to define urban terrain features, such as buildings, roads, parks, and train stations. The format is described in Appendix A.

9.5.2 Command Line Configuration

To use Urban Terrain Data format for terrain features data, include the following parameters in the scenario configuration (.config) file:

```
URBAN-TERRAIN-TYPE          QUALNET-URBAN-TERRAIN
TERRAIN-FEATURES-SOURCE     FILE
```

Urban Terrain Parameters

Table 9-12 describes the Urban Terrain parameters. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 9-12. Urban Terrain Parameters

Parameter	Value	Description
`TERRAIN-FEATURES-FILE` *Optional* (see note below table) *Scope:* Global	Filename	Name of the file that contains urban terrain data. The file is in QualNet Terrain Format (see Section 9.5.2.1). **Note:** This parameter must be used if only one file is used to describe urban terrain.
`TERRAIN-FEATURES-FILENAME` *Optional* (see note below table) *Scope:* Global *Instances:* file index	Filename	Name of the file that contains urban terrain data. The file is in QualNet Terrain Format (see Section 9.5.2.1). **Note:** This parameter must be used if multiple files are used to describe urban terrain. Include as many instances of this parameter as the number of files used to describe building and road features.
`TERRAIN-FEATURES-FILELIST` Optional (see note below table) *Scope:* Global	Filename	Specifies the name of file that lists the files that contain urban terrain data in QualNet Terrain Format.

TABLE 9-12. Urban Terrain Parameters (Continued)

Parameter	Value	Description
TERRAIN-FEATURES-SUBTRACT-TERRAIN-ELEVATION *Optional* *Scope:* Global	List: • YES • NO *Default:* NO	Indicates whether terrain elevation (ground level) should be subtracted from the altitude for all terrain features. YES : The ground elevation is subtracted from the node's elevation. NO : The node's elevation is not modified.

Note: One and only one of the parameters TERRAIN-FEATURES-FILE, TERRAIN-FEATURES-FILENAME, and TERRAIN-FEATURES-FILELIST must be included in the configuration file.

9.5.2.1 QualNet Terrain Format

The QualNet Terrain Format is described in Appendix A. Urban terrain features data files in QualNet Terrain Format can be generated in the following ways:

- ESRI shapefiles can be converted into QualNet Terrain Format. To do this, set the parameter TERRAIN-FEATURES-SOURCE to SHAPEFILE, specify the shapefile parameters (see Section 9.4.5), and run the simulation. QualNet Terrain Format files representing the buildings and roads features are generated from the shapefiles and used in the simulation. The QualNet Terrain Format files that are generated can be reused in later simulations by setting the parameter TERRAIN-FEATURES-SOURCE to FILE.
- QualNet Terrain Format files can also be generated from ESRI shapefiles by using the Shapefile-to-XML utility program. Refer to *EXata User's Guide* for details of this utility program.
- The Urban Grid script can be used to generate files in QualNet Terrain Format for simple urban terrain descriptions. Refer to *EXata User's Guide* for details of this script.
- QualNet Terrain Format files can be created manually by creating a new file or modifying an existing file.

9.5.3 GUI Configuration

To configure the Urban Terrain Data format parameters, perform the following steps:

1. Go to the **Scenario Properties Editor > Terrain**.

2. Set **Urban Terrain Features Format** to *QualNet Format*, and **Urban Terrain Features Format** to *QualNet Terrain File*.

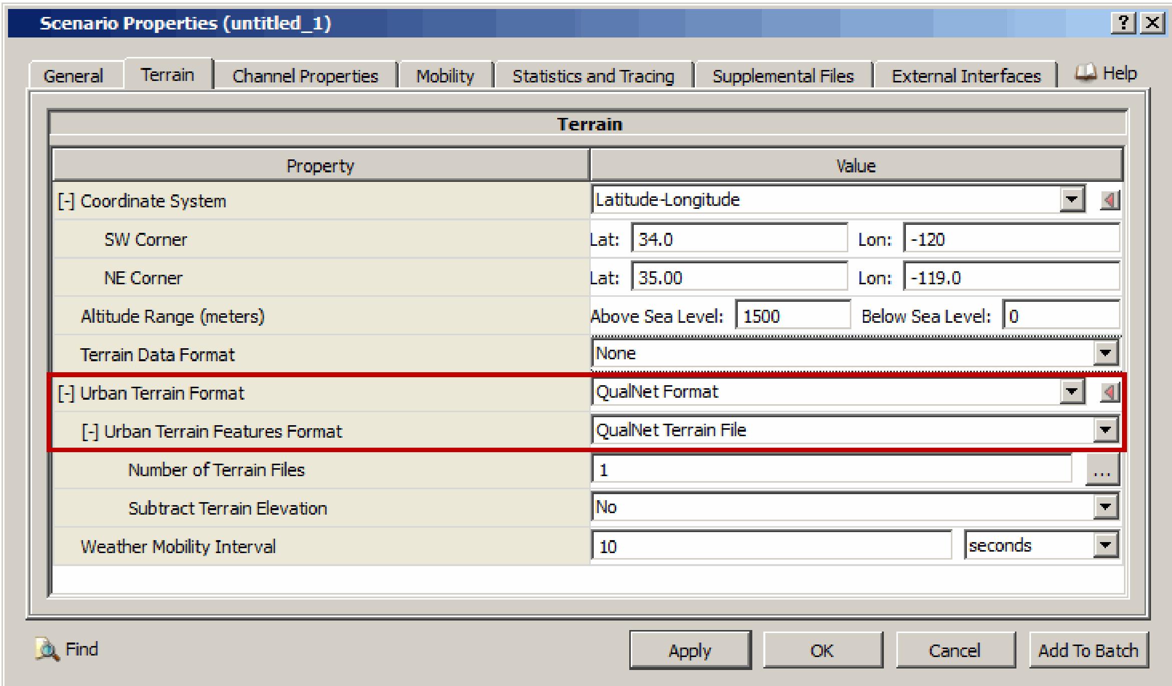


FIGURE 9-5. Enabling Urban Terrain Data Format

3. Set the dependent parameters listed in Table 9-13.

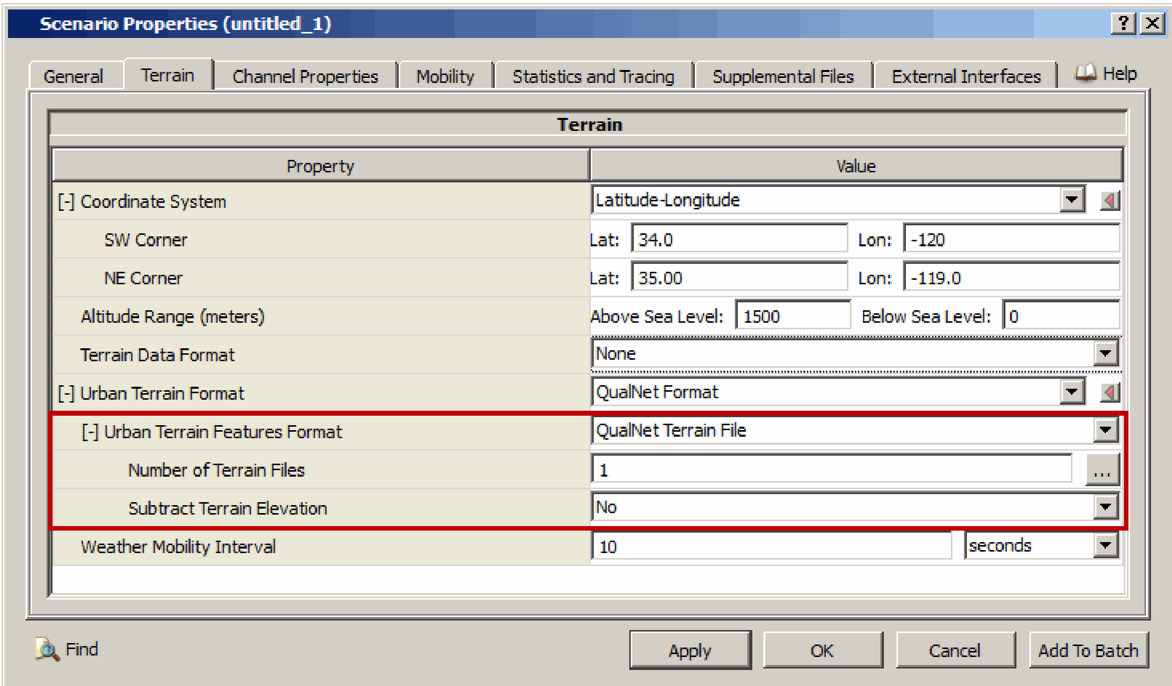


FIGURE 9-6. Setting Urban Terrain Data Format Parameters

TABLE 9-13. Command Line Equivalent of Urban Terrain Data Format Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Number of Terrain Files	Global	N/A
Subtract Terrain Elevation	Global	`TERRAIN-FEATURES-SUBTRACT-TERRAIN-ELEVATION`

Setting Parameters

- Set **Number of Terrain Files** to the number of terrain data files used in the scenario.

4. To specify the names of the terrain files, do the following:

a. Click on the **Open Array Editor** ... button in the **Value** column for **Number of Terrain Files**. This opens the Array Editor.

b. In the left panel of the Array Editor, select the file index. In the right panel, specify the name of the selected file. Click **OK** to close the Array Editor.

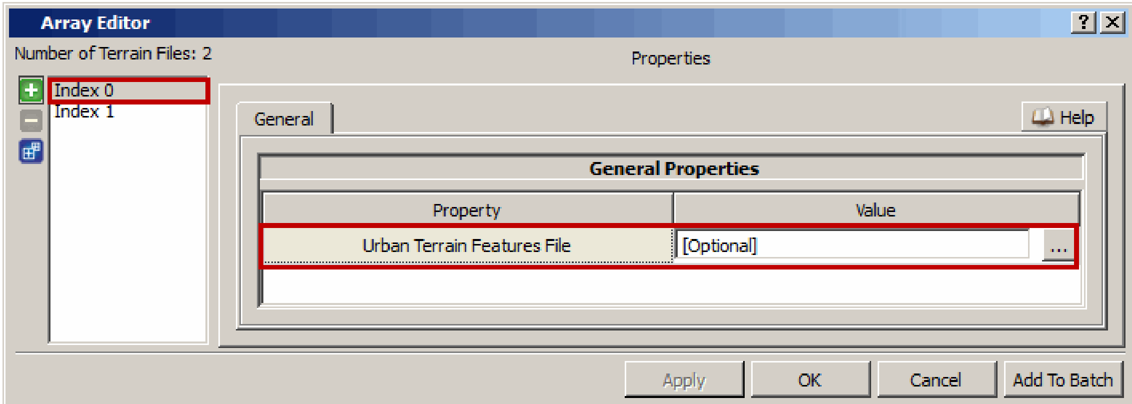


FIGURE 9-7. Specifying Urban Terrain File

TABLE 9-14. Command Line Equivalent of Urban Terrain Data Format Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Urban Terrain Features File [*i*]	Global	`TERRAIN-FEATURES-FILENAME[i]`

Setting Parameters

- Set **Urban Terrain Features File [i]** to the name of the ith urban terrain feature file. See Section 9.5.2.1 for details.

9.5.4 Statistics

There are no statistics collected for the Urban Terrain model.

9.5.5 Scenarios Included in QualNet

The EXata distribution includes several sample scenarios for the Urban Terrain model. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/terrain-features. Table 9-15 lists the sub-directory where each scenario is located.

TABLE 9-15. Urban Terrain Scenarios Included in EXata

Scenario	Description
UrbanEnv	To show how to use terrain files which are in QualNet terrain format.

9.5.6 References

None.

10 Miscellaneous Models

This chapter describes features, configuration requirements and parameters, statistics, and scenarios for Miscellaneous Models, and consists of the following sections:

- Battery Models
- Weather Pattern Model

10.1 Battery Models

10.1.1 Description

Battery models capture the characteristics of real-life batteries, and can be used to predict their behavior under various conditions of charge/discharge. Battery models are useful tools for a battery-driven system design approach, because they enable analysis of the discharge behavior of the battery under different design choices (for example, system architectures, power management policies, and transmission power control), without resorting to time consuming (and expensive) prototyping and measurement for each alternative.

10.1.1.1 Energy and System Model

Battery provides voltage and current for the components attached to the battery such as radio interfaces, CPU, Memory blocks, sensing core, etc. A DC-DC converter regulates voltage for different components (see Figure 10-1). Battery is a repository of electrical charges which losses its charge when a load (electrical current) is taken off from it. The loss rate is a function of the load.

The total energy consumed by the system per cycle is the sum of energies consumed by the radio transceivers (E_{Trans}) protocol processor (E_{CPU}), the DC-DC converter (E_{DC}) and the efficiency losses in the battery (E_{Bat}).

$$E_{Cycle} = E_{Trans} + E_{CPU} + E_{DC} + E_{Bat} \qquad (1)$$

The total energy consumed during the execution of the software on a given hardware architecture is the sum of the energies consumed during each cycle. Models for energy consumption and performance estimation of each system component are described in the following sections.

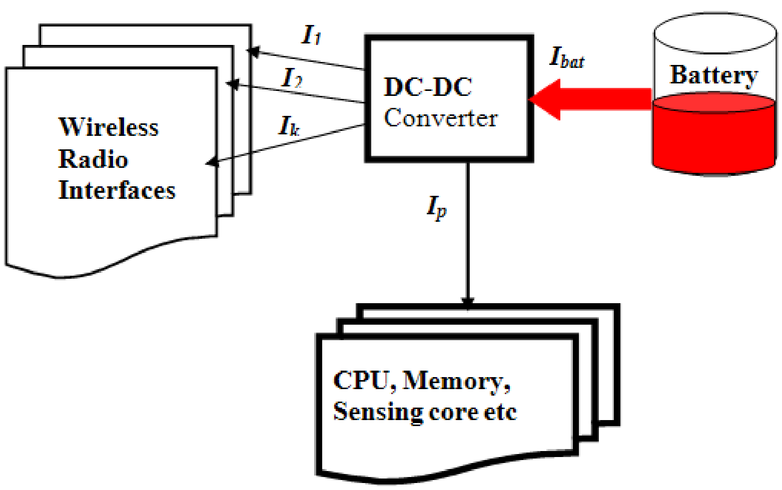


FIGURE 10-1. System Level Block of Smart Batteries

10.1.1.2 Derived Battery Model

Based on the above discussion, we can draw the following conclusions regarding the various battery models: In terms of flexibility, the electro-chemical models are the least flexible, making it difficult to use them for modeling any given battery. On the other hand, configuring the circuit level models, analytical models and the stochastic models for different types of batteries is relatively easy. Additionally, the electro-chemical models being principally targeted to designers and manufacturers of batteries rather than systems, make use of many proprietary parameters which are typically unavailable to a system designer. In terms of accuracy and efficiency, the electro-chemical models are the most accurate and also the most computation intensive.

Analytical models are at the other extreme, being computationally efficient, but limited in the discharge effects that they model. Electrical circuit models can be simulated with high efficiency, ignoring the effects of recovery of charge during idle periods.

The stochastic model can be efficiently used in a simulation framework and is capable of modeling rate capacity as well as recovery effects.

10.1.1.3 EXata Battery Models

This section describes the battery models implemented in EXata.

10.1.1.3.1 Service Life Battery Model

This model estimates the total service life of the battery (i.e., the time it takes the battery charge to reach zero from the start of simulation).

The employed battery model is a modular approach for enhancing event-driven simulator with precise high battery level which can accurately estimate service life of a battery-operated device with a given -time-varying load. Moreover, the methodology used here has tightly coupled component models, thus making the approach more accurate. Performance and energy computed by the simulator are within a few percent tolerance of hardware measurements on the SmartBadge. The battery model used here is developed by Sarma and Rakhmatov in [1]. Rakhmatov model was selected because it is the most accurate analytical model. The other models required solving Partial Differential Equations (PDEs) etc., which are difficult to optimize.

Parameter Estimation

Rakhmatov's model is an abstraction of a real battery. For the model to adequately mimic real behavior of the batteries, it is recommended to choose the appropriate parameters so that the predicted and observed lifetimes match closely. Thus, before one can use the proposed model, the parameters need to be estimated from experimental data for the modeled battery. Simple experiments with constant loads are sufficient for estimation purposes and one can utilize the following equation:

$$\alpha \approx I\left[L + 2\sum_{m=1}^{10}\frac{1-e^{-\beta^2 m^2 L}}{\beta^2 m^2}\right] \qquad (2)$$

For a given battery under a given load, the battery voltage changes over time from the open-circuit value, V_{open}, to some cutoff value, V_{cutoff}. The observed lifetime is defined as the time when the battery voltage reaches V_{cutoff}. The predicted lifetime is defined as the time for which the equality (2) holds. For a given set of constant loads $\{I_{(1)}, I_{(2)}, \ldots, I_{(M)}\}$, the corresponding set of observed lifetimes is $\{L_{(1)}, L_{(2)}, \ldots, L_{(M)}\}$. The objective is to find and such that the predicted lifetimes match the observed lifetimes as closely as possible. However, this objective is hard to pursue directly, since (2) is hard to solve for the unknown L. Alternatively, one can estimate parameters by fitting the load values for a given set of observed lifetimes. Let $\hat{I}(k)$ denote the fitted value of $I_{(k)}$. According to [1]:

$$\hat{I}(k) \approx \frac{\alpha}{\left[L(k) + 2\sum_{m=1}^{10} \frac{1 - e^{-\beta^2 m^2 L}}{\beta^2 m^2} \right]} \qquad (3)$$

The objective now is to estimate the parameters α and β such that $\hat{I}(k)$ matches $I_{(k)}$ as closely as possible for all 1 ≤ *k* ≤ *M*. A standard least-squares estimator is employed for this purpose and the model parameters are selected so that

$$\sum_{k=1}^{M} \left| \hat{I}(k) - I(k) \right|$$

is minimized.

To implement this model you need to use the following steps:

1. Get the data sheet of a battery that models rated capacity (in Ahr) vs. discharge current (in hour).
2. Do the curve fitting to get β parameters for Rakhmatov's model.
3. Use the optimized model to generate a *.pcm* file.
4. The semantics of *pcm* file is excess consumption versus time, and each entry represents time interval of one second. The first line means that after one second, if a unit load is applied the battery will be drained by X amount. Notice that the excess amount decreases as time increases and asymptotically reaches 1.

10.1.1.3.2 Residual Life Battery Model

This model estimates the remaining service life of the battery at any time in the simulation.

Battery Capacity and Efficiency

One important characteristic of the battery is that some amount of energy will be wasted when the battery is delivering the energy required by the circuit. In analytical form, given a fixed battery output voltage, if the circuit current requirement for the battery is 1, the actual current that is taken out of the battery is

$$I^{act} = \frac{I^{bat}}{\mu}, \; 0 < \mu \leq 1 \qquad (4)$$

where μ is called the battery efficiency (or utilization) factor. I^{act} is always larger than or equal to I^{bat}.

Defining CAP^{0} as the amount of energy that is stored in a new (or fully charged) battery and CAP^{act} as the actual energy that can be used by the circuit, (4) is equivalent to:

$$CAP^{act} = \mu . CAP^{0} \qquad (5)$$

The efficiency factor μ is a function of discharge current I^{bat}:

$$\mu = f(I^{bat})$$

where, *f*(.) is a monotonically decreasing function. Only the low-frequency part of the current is relevant to changing the battery efficiency. Therefore, I^{bat} must be the average output current of the battery (denoted by *i*(t)) over certain amount of time, which can be represented as *N.T*, where *N* is some positive integer and *T* is the clock cycle, as shown in the equation below. *N.T* may be as large as a few seconds.

$$I^{bat} = \frac{1}{N \cdot T} \int_{0}^{N \cdot T} i(t) \cdot dt \qquad (5)$$

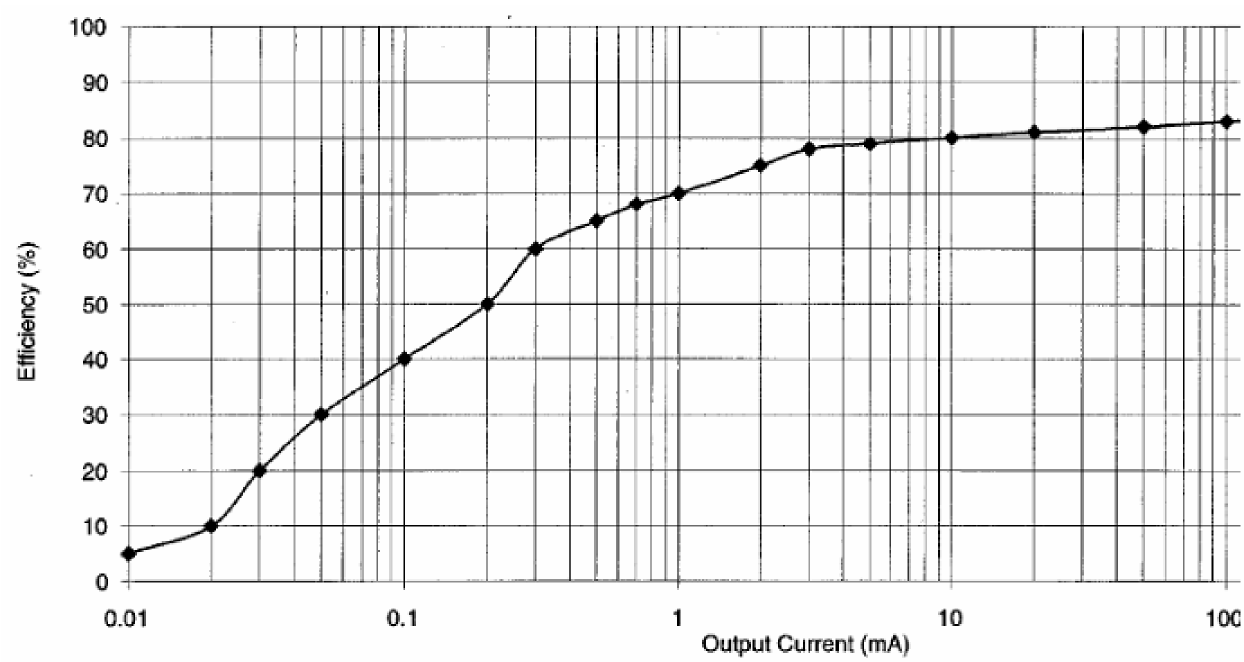


FIGURE 10-2. Battery Efficiency

The actual capacity of the battery decreases when the discharge current increases. With discharge current ratio, the battery efficiency is estimated using the battery efficiency plot such as the one shown in Figure 10-2.The Y-axis is efficiency or utilization, whereas the X-axis is the output current of battery, I^{bat}.

Given the battery capacity model described above, battery estimation is performed as follows. First, the designer characterizes the battery with its rated capacity, the time constant and the table of points describing the discharge plot similar to the one shown in Figure 10-2. During each simulation cycle (i.e., *N.T*) discharge current ratio is computed from the rated battery current. Efficiency is calculated using linear interpolation between the points from the discharge plot. Lower efficiency means that less battery energy remains and thus the battery lifetime is proportionally lower. For example, if battery efficiency is 60% and its rated capacity is 100 mAhr at 1 V, then the battery would be drained in 12 min at an average DC-DC current of 300 mA. With efficiency of 100% the battery would last 1 h.

10.1.1.3.3 Linear Battery Model

This model is a simple linear model which is based on the coulomb counting technique. The coulomb counting technique accumulates the dissipated coulombs from the beginning of the discharge cycle and estimates the remaining capacity based on the difference between the accumulated value and a pre-recorded full-charge capacity. This method can lose some of its accuracy under variable load condition because it ignores the non-linear discharge effect during the coulomb counting process.

The battery is discharged linearly as a function of discharge current load.

10.1.2 Features and Assumptions

This section describes the implemented features, omitted features, assumptions and limitations of the Battery models.

10.1.2.1 Implemented Features

- Implementation of a model for accurate estimation of service life of a battery. This model captures the following contributing factors:
  - *Battery rate capacity effect*: the model which precisely estimates non-linearity effect of rated capacity versus discharge current load.
  - *Charge recovery effect*: the model takes into account the actual phenomenon that battery charge increases when no discharge current load is drawn from the battery for a given period of time.
- Implementation of a model for fairly good prediction of remaining residual life of the battery. The model captures non-linearity of rated capacity versus discharge current load (i.e. *Battery rate capacity effect*) by introducing utilization function.
- Implementation of a simple linear model based on the Columbus Count method. In this method the battery is discharged linearly over its service life and the rate of discharge at any time is the current which is drawn from battery.
- Battery charge level monitoring: The state of charge of the charge of the batteries attached to a battery-operated node is periodically checked and if the battery is out of charge the node is shut down (currently inserting permanent faults on all network interfaces attached to the node.)
- User configurable battery type: The battery models are generic and parametric models. For the model specification the input parameters must be configured initially for a given battery type from a battery manufacturer.
  - *Service Life Battery Model*: We have precomputed and stored parameters and specifications for several types of batteries including DURACELL(AA and AAA) and ITSY. Therefore, for DURACELL (AA and AAA) and ITSY battery types the specification can be loaded from battery library.
  - *Residual Life Battery Model*: A lookup table of which specifies efficiency as a function of output current of battery (in mA) is computed from data sheet of any given battery. We have computed and stored the specifications for several types of batteries including DURACELL (AA and AAA) and PANASONIC. Therefore, for DURACELL (AA and AAA) and PANASONIC battery types the specification can be loaded from battery library.

10.1.2.2 Omitted Features

None.

10.1.2.3 Assumptions and Limitations

The following assumptions are made in the implementation of the battery models:

- The output voltage of the battery is considered to be constant during the operation of the battery. Note that in data sheet of a battery the rated capacity versus load has different plots for different output voltages of a battery. Furthermore, note that output voltage of a battery decreases as depth of discharge (ratio of remaining charge to full charge) increases. Fore more accurate modeling, it's suggested to derive the model parameters from the capacity-load curve measured at average output voltage during service life of the battery.

- The effects of temperature and cycle-aging have not been captured in any of the model which has been currently implemented in the simulator.
- DC-DC model which estimates energy or power lost in DC-DC converter. The converter adjusts output voltage for different components (i.e. to enable different wireless radio interfaces to operate at different voltages.)

10.1.3 Command Line Configuration

To specify the Service Life battery model, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   BATTERY-MODEL         SERVICE-LIFE-ACCURATE
```

To specify the Residual Life battery model, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   BATTERY-MODEL         RESIDUAL-LIFE-ACCURATE
```

To specify the Linear battery model, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>]   BATTERY-MODEL         LINEAR
```

The scope of the parameter `BATTERY-MODEL` can be Global and Node. See Section 1.2.1.1 for a description of `<Qualifier>` for each scope.

> **Note:** The default value of the parameter `BATTERY-MODEL` is `NONE`. If the battery model is not defined or defined as `NONE`, no battery model is employed.

Table 10-1 describes the general parameters for battery models. Table 10-2 describes the parameters for the Service Life battery model. Table 10-3 describes the parameters for the Residual Life battery model. Table 10-4 describes the parameters for the Linear battery model.

See Section 1.2.1.3 for a description of the format used for the parameter tables.

General Battery Model Parameters

Table 10-1 shows the general parameters for battery models.

TABLE 10-1. General Battery Model Parameters

Parameter	Value	Description
BATTERY-TYPE Optional *Scope:* Global, Node	List: • DURACELL-AA • DURACELL-AAA • ITSY • DURACELL-AAA-MN-2400 • DURACELL-AAA-MX-2400 • DURACELL-AA-MX-1500 • PANASONIC-AA • PANASONIC-AAA	This parameter specifies the type of the battery which is used. For the SERVICE-LIFE-ACCURATE battery model, battery type can be one of the following: • DURACELL-AA • DURACELL-AAA • ITSY For the RESIDUAL-LIFE-ACCURATE battery model, battery type can be one of the following: • DURACELL-AAA-MN-2400 • DURACELL-AAA-MX-2400 • DURACELL-AA-MX-1500 • PANASONIC-AA • PANASONIC-AAA
BATTERY-MODEL-STATISTICS *Scope:* Global, Node	List: • YES • NO *Default:* NO	This parameter enables collection of statistics for the battery model.

Service Life Battery Model Parameters

Table 10-2 describes the parameters to configure the Service Life battery model.

TABLE 10-2. Service Life Battery Model Parameters

Parameter	Value	Description
BATTERY-CHARGE-MONITORING-INTERVAL Optional *Scope:* Global, Node	Time *Range:* ≥ 0S *Default:* 1M	This parameter specifies the interval in which the state of charge of the battery is monitored once. In case the battery is out of charge, the node is shut down.
BATTERY-PRECOMPUTE-TABLE-FILE Required *Scope:* Global, Node	Filename	This parameter specifies the file that contains the pre-computed table for the specified battery type. **Note:** A pre-computed table file for each of the battery types can be found in EXATA_HOME/data/battery. The names of the files for the different battery models are: DURACELL-AA : duracell-aa.pcml DURACELL-AAA : duracell-aaa.pcm ITSY : itsy.pcm

Residual LIfe Battery Model Parameters

Table 10-3 describes the parameters to configure the Residual Life battery model.

TABLE 10-3. Residual Life Battery Model Parameters

Parameter	Value	Description
BATTERY-CHARGE-MONITORING-INTERVAL Optional *Scope:* Global, Node	Time *Range:* ≥ 0S *Default:* 1M	This parameter specifies the interval in which the state of charge of the battery is monitored once. In case the battery is out of charge, the node is shut down.
BATTERY-LOAD-UTILITY-TABLE-FILE Required *Scope:* Global, Node	Filename	This parameter specifies the file that contains battery utilization versus current load for the specified battery type. See note below.

Note: A load utility table file for each of the battery types can be found in EXATA_HOME/data/battery. The names of the files for the different battery models are:

DURACELL-AAA-MN-2400 : DURACELL-MN2400.utl

DURACELL-AAA-MX-2400 : DURACELL-MX2400.utl

DURACELL-AA-MX-1500 : DURACELL-MX2400.utl

PANASONIC-AA : PANASONIC-AA.utl

PANASONIC-AAA : PANASONIC-AAA.utl

Linear Battery Model Parameters

Table 10-4 describes the parameters to configure the Linear battery model.

TABLE 10-4. Linear Battery Model Parameters

Parameter	Value	Description
BATTERY-CHARGE-MONITORING-INTERVAL Optional *Scope:* Global, Node	Time *Range:* ≥ 0S *Default:* 1M	This parameter specifies the interval in which the state of charge of the battery is monitored once. In case the battery is out of charge, the node is shut down.
BATTERY-INITIAL-CHARGE Optional *Scope:* Global, Node	Real *Range:* ≥ 0.0 *Default:* 1200 *Unit:* mAhr	This parameter specifies the value of full battery capacity in mAhr for the Linear Model.

10.1.4 GUI Configuration

This section describes how to configure Battery Model in the GUI.

Configuring Battery model Parameters

To configure the battery Model parameters, perform the following steps:

1. Go to **Default Device Properties Editor > Node Configuration > Battery Model**.
2. Set **Battery Model** to the desired model as shown in Figure 10-3.

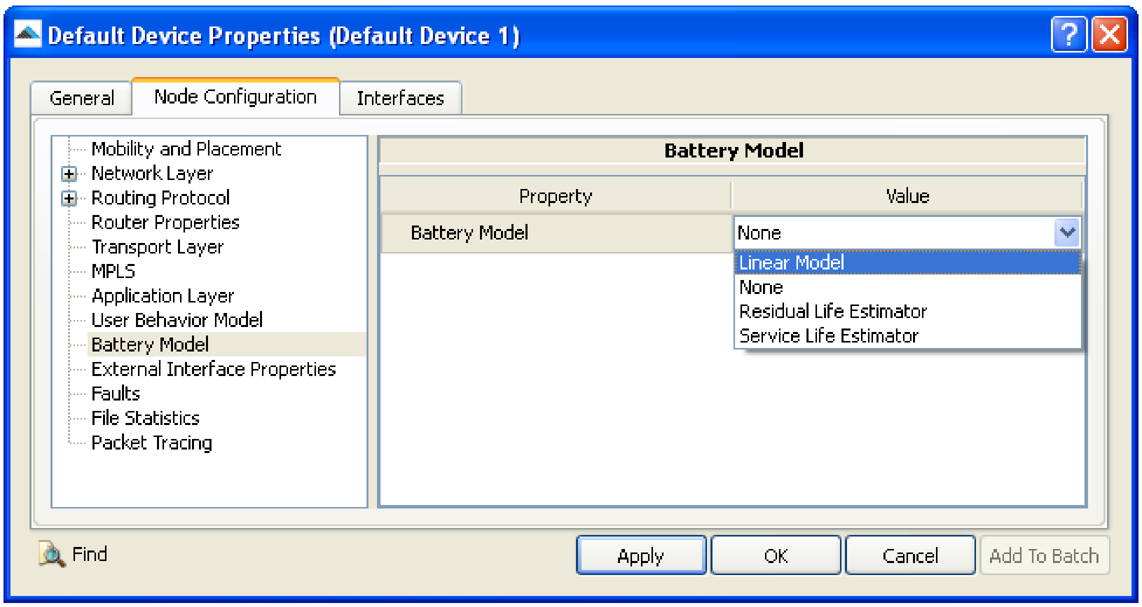


FIGURE 10-3. Setting Battery Model

TABLE 10-5. Command Line Equivalent of Battery Model Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Battery Model	Node	`BATTERY-MODEL`

3. If **Battery Model** is set to be *Linear Model,* set the dependent parameters listed in Table 10-6.

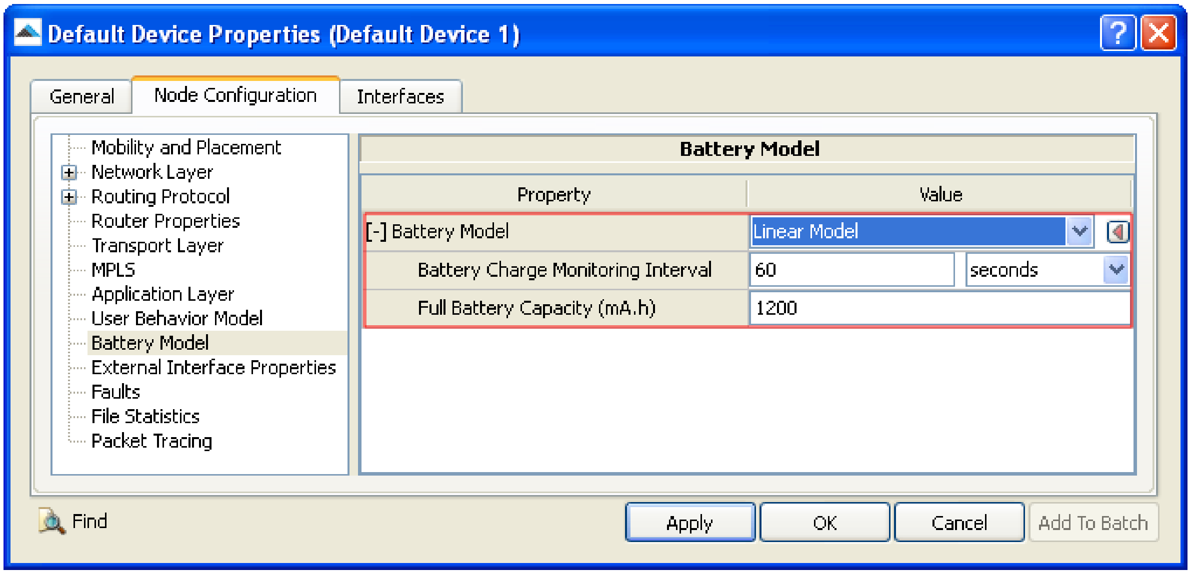


FIGURE 10-4. Setting Linear Model Parameters

TABLE 10-6. Command Line Equivalent of Linear Model Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Battery Charge Monitoring Interval	Node	`BATTERY-CHARGE-MONITORING-INTERVAL`
Full Battery Capacity	Node	`BATTERY-INITIAL-CHARGE`

4. If **Battery Model** is set to be *Residual Life Estimator*, set the dependent parameters listed in Table 10-7.

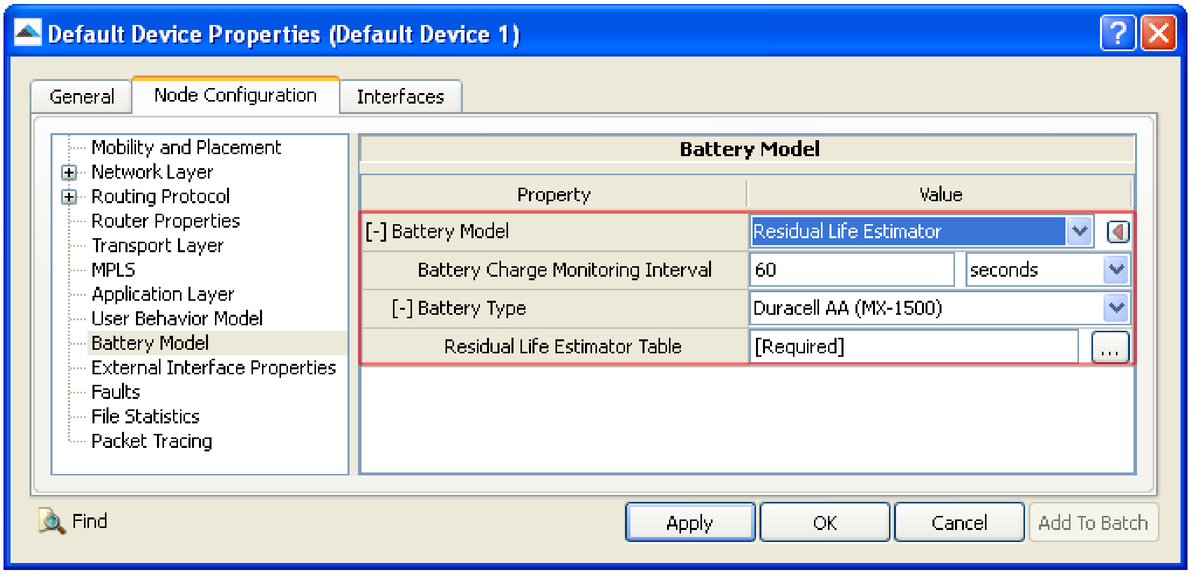


FIGURE 10-5. Setting Residual Life Estimator Model Parameters

TABLE 10-7. Command Line Equivalent of Residual Life Estimator Model Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Battery Charge Monitoring Interval	Node	`BATTERY-CHARGE-MONITORING-INTERVAL`
Battery Type	Node	`BATTERY-TYPE`
Residual Life Estimator Table	Node	`BATTERY-LOAD-UTILITY-TABLE-FILE`

Setting Parameters

- Select the desired **Battery Type** and set **Residual Life Estimator Table** to the name of the Load Utility Table file.

5. If the **Battery Model** is set to be *Service Life Estimator*, set the dependent parameters listed in Table 10-8.

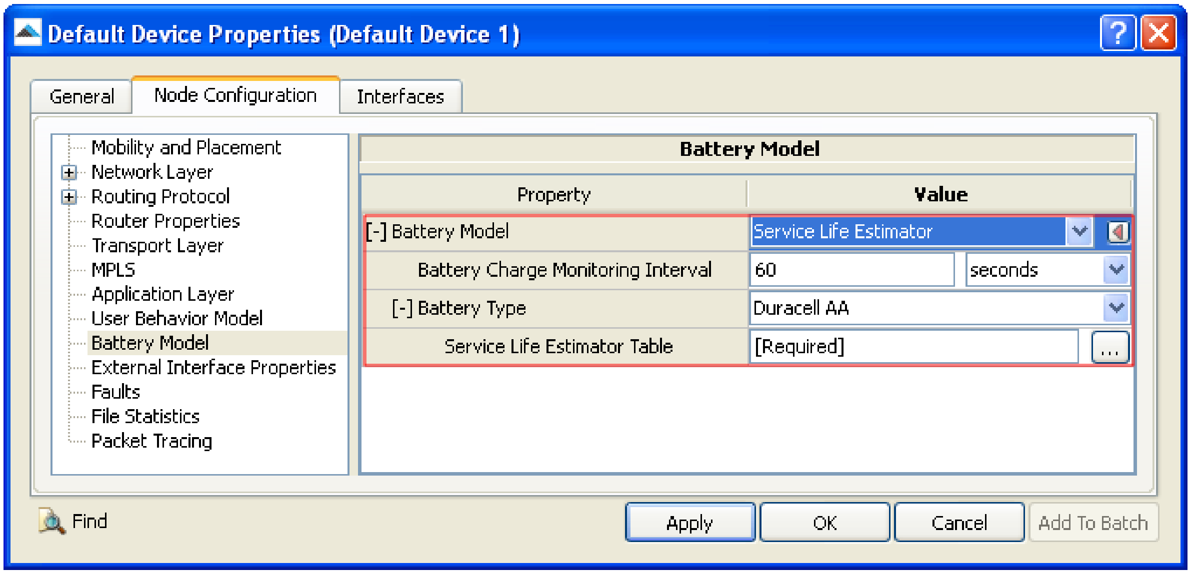


FIGURE 10-6. Setting Service Life Estimator Model Parameters

TABLE 10-8. Command Line Equivalent of Service Life estimator Model Specific Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Battery Charge Monitoring Interval	Node	`BATTERY-CHARGE-MONITORING-INTERVAL`
Battery Type	Node	`BATTERY-TYPE`
Service Life Estimator Table	Node	`BATTERY-PRECOMPUTE-TABLE-FILE`

Setting Parameters

- Select the desired **Battery Type** and set **Service Life Estimator Table** to the name of the Battery Precompute Table file.

Configuring Statistics Parameters

Statistics for Battery Model can be collected at the global and node levels. See Section 4.2.9 of *EXata User's Guide* for details of configuring statistics parameters.

To enable statistics collection for Battery models, check the box labeled **Battery Model** in the appropriate properties editor.

TABLE 10-9. Command Line Equivalent of Statistics Parameters

GUI Parameter	Scope of GUI Parameter	Command Line Parameter
Battery Model	Global, Node	`BATTERY-MODEL-STATISTICS`

10.1.5 Statistics

This section describes the file and dynamic statistics of the Battery model.

10.1.5.1 File Statistics

Table 10-10 shows the Battery model statistics that are output to the statistics (.stat) file at the end of simulation.

TABLE 10-10. Battery Model Statistics

Statistic	Description
Residual battery capacity (in mAhr)	Specifies the remaining charge of the battery attached to the node at the end of simulation. **Note:** If no battery model is defined for a node, the total charge consumed (in mAhr) by a node is reported in the statistics file.
Total charge consumed (in mAhr)	Specifies the total charge consumed by a node.
Battery is dead at time (Sec)	If during simulation run, the battery of a node is completely discharged, this statistic shows the time (in seconds) in which the battery charge of a node reaches zero.

10.1.5.2 Dynamic Statistics

The following dynamic statistics are enabled for the Battery model (refer to Chapter 6 of *EXata User's Guide* for details of viewing dynamic statistics in the GUI during the simulation):

- Battery Charge (mAhr)
- Electrical Load (mA)

10.1.6 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the Battery model. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/battery-models. Table 10-11 lists the sub-directory where each scenario is located.

TABLE 10-11. Battery Model Scenarios Included in EXata

Scenario Sub-directory	Description
battery-dieout\Linear-model-case	To test the case that simple linear battery model is configured for the nodes in the network. The batteries of few nodes are depleted and those nodes die out during simulation time. The death times for those nodes are reported in .stat file.
battery-dieout\RLA-model-case	To verify Residual Life Accurate (RLA) battery model with the battery type configured as Panasonic AAA size. The batteries of few nodes are depleted and those nodes die out during simulation time. The death times for those nodes are reported in .stat file.
battery-dieout\SLA-model-case	To verify Service Life Accurate (SLA) battery model with the battery type configured as ITSY battery type.
battery-linear-model	To test the case that simple linear battery model is configured for the nodes in the network.
battery-no-model	To test the case that no battery model is configured for the nodes in the network. Cumulative consumed charge is printed in the .stat file when no battery model is selected

TABLE 10-11. Battery Model Scenarios Included in EXata (Continued)

Scenario Sub-directory	Description
battery-RLA-model\Case-1	To verify Residual Life Accurate (RLA) battery model with the battery type configured as Panasonic AAA size.
battery-RLA-model\Case-2	To verify Residual Life Accurate (RLA) battery model with the battery type configured as DURACELL MX1500 AAA size.
battery-SLA-model\Case-1	To verify Service Life Accurate (SLA) battery model with the battery type configured as ITSY battery type.
battery-SLA-model\Case-2	To verify Service Life Accurate (SLA) battery model with the battery type configured as DURACELL AA battery type.
mixed-models	To verify all supported battery models.

10.1.7 References

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10.2 Weather Pattern Model

10.2.1 Description

User-specified weather patterns that move and affect propagation. Currently, the weather pattern model supports latitude/longitude coordinates. In addition to the parameters specified here, the most important parameter related to the weather implementation is the channel frequency. Higher frequency signals are more affected by the weather.

10.2.2 Command Line Configuration

To specify weather patterns in a scenario, include the following parameter in the scenario configuration (.config) file:

```
[<Qualifier>] WEATHER-CONFIG-FILE      <weather-file>
```

where

`<weather-file>`	Name of the weather pattern configuration file. The format of this file is described in Section 10.2.2.1.

Weather Pattern Parameters

Table 10-12 describes the Weather Pattern parameters specified in the scenario configuration (.config) file. See Section 1.2.1.3 for a description of the format used for the parameter table.

TABLE 10-12. Weather Pattern Configuration Parameters

Parameter	Value	Description
`WEATHER-MOBILITY-INTERVAL` *Optional* *Scope:* Global, Node	Time *Range:* `> 0S` *Default:* `10S`	Specifies the interval at which weather patterns move.

10.2.2.1 Format of the Weather Pattern Configuration File

The weather pattern configuration file specifies the shape and characteristics of one or more weather patterns as well as the movement of the patterns.

The shape and characteristics of a weather pattern are specified using the following format:

```
WEATHER-PATTERN[<id>] (<corner-1>;<corner-2>;...;<corner-n>)
<altitude> <intensity> <polarization> <hierarchy ID>
```

where

`<id>`	Unique ID for the weather pattern. This is a non-negative integer . The ID for the first pattern is 0, and the others are numbered sequentially.
`<corner-i>`	Coordinates of the i^{th} corner of the polygon that defines the weather pattern. Each corner is specified in the following format: `<lat>, <lon>` where `<lat>` : Latitude of the corner `<lon>` : Longitude of the corner **Note:** Coordinates should be given in high precision, and be at least 10 significant digits.
`<altitude>`	Altitude of the weather pattern in meters.
`<intensity>`	Precipitation in millimeters per hour.
`<polarization>`	Antenna type being modeled. This can be `HORIZONTAL` or `VERTICAL`.
`<hierarchy ID>`	Position of the weather pattern in EXata GUI. A value of 0 indicates the outermost level.

Note: All parameters must be specified on the same line.

Example

The following is an example weather pattern consisting of a polygon of five points:

```
WEATHER-PATTERN[0]
(22.318367,131.631;22.448,133.926;24.155,134.308;25.346,132.788;
24.212,130.425)1000.0 10.0 HORIZONTAL 0
```

Weather movement is specified as a series of waypoints, which are interpreted as new positions for the first corner of the weather pattern. The other corners of the weather pattern maintain their positions relative to the first corner.

The format of a waypoint is:

```
<id> <arrival time> (<lat>,<lon>)
```

where

`<id>`	ID of the weather pattern.
`<arrival time>`	Arrival time of the weather pattern at this waypoint.

`<lat>`	New latitude of the first corner of the weather pattern.
`<lon>`	New longitude of the first corner of the weather pattern.

Example

The following are examples of waypoints that specify future positions of weather pattern 0:

```
0 120S (21.820408163265718,132.61484467301395)
0 240S (21.151020408163113,133.52699979150717)
0 400S (20.80000000000036,135.02988393912017)
0 800S (20.702040816326285,137.41017443880708)
```

10.2.3 GUI Configuration

In the GUI, a weather pattern is configured by drawing its shape on the canvas (in the form of a polygon). The weather pattern properties are configured using the Weather Pattern Editor.

10.2.3.1 Creating Weather Patterns

To specify a weather pattern, perform the following steps:

1. Select the **Weather Pattern**  button from the **Other Components** toolbar of the **Standard Toolset**.
2. Draw the polygon representing the weather pattern by clicking on the canvas locations corresponding to the corners of the polygon. When you add a new point, lines is drawn from the last point to new point and the very first point to the new point.
3. After placing the last corner of the polygon, press the right mouse button.
4. You can start drawing another weather pattern polygon by clicking on the canvas at successive corner locations and end by right-clicking.
5. To end the weather pattern insert mode, press the right mouse button again.

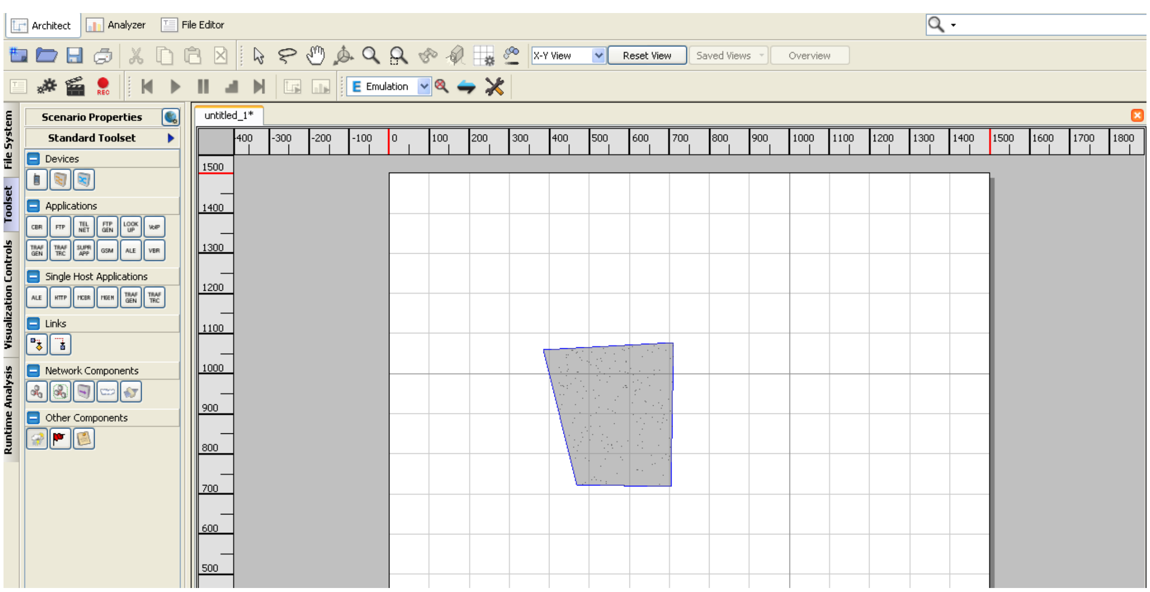

FIGURE 10-7. Drawing a Weather Pattern

Mobility can be added to a weather pattern in the same manner as a node. Note that after clicking on a weather object with the waypoint tool selected, a shadow of the weather object will follow the mouse pointer to indicate what area the weather will cover.

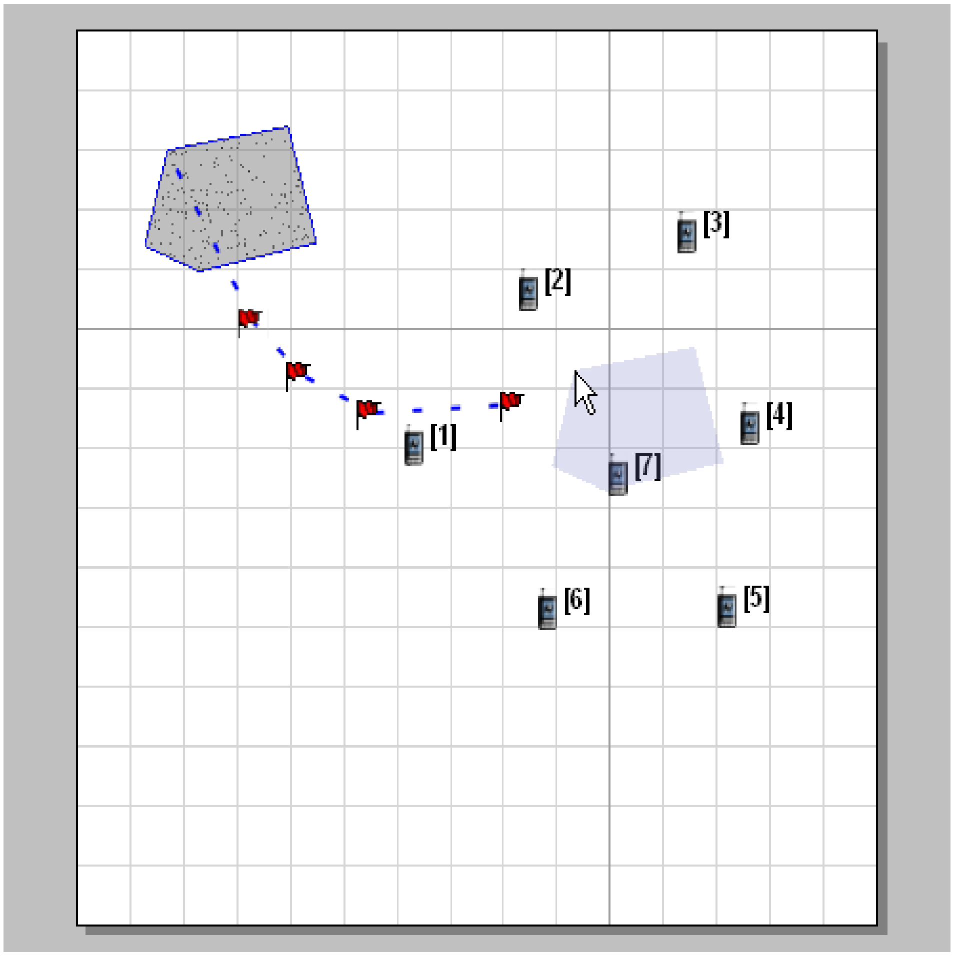

FIGURE 10-8. Adding Mobility to Weather Pattern

10.2.3.2 Modifying Properties Using Weather Properties Editor

The Weather Properties Editor is used to change characteristics of weather objects such as height and intensity.

To open the Weather Properties Editor, right-click on a weather object and select **Properties**. You can also open the Weather Properties Editor by selecting **Weather Properties** from the **Tools** menu of Architect. Figure 10-9 shows the Weather Properties Editor for a scenario with two weather objects.

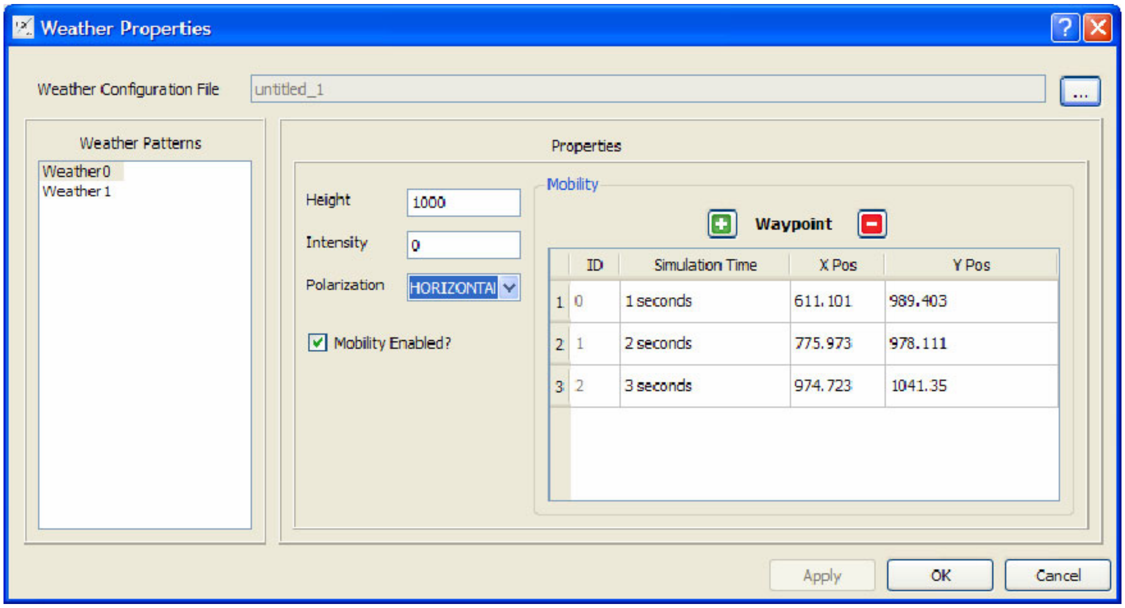

FIGURE 10-9. Weather Properties Editor

1. To select a weather pattern, click on the corresponding entry in the list box on the left.
2. To change the properties of a weather pattern, use the corresponding edit and combo boxes. From here, you can specify the height of the weather off the ground (in meters), the intensity, and the polarization (horizontal or vertical).
3. To add mobility waypoints to a weather object with no mobility previously defined, select the **Mobility Enabled** check box. Then click the  button to start adding waypoints.
4. To edit the arrival times and positions of waypoints, use the table on the right. Note that weather patterns cannot change height over time in an EXata scenario. Therefore, the Z positions of the waypoints cannot be specified individually and are instead taken from the height specified for the weather.

10.2.4 Scenarios Included in EXata

The EXata distribution includes several sample scenarios for the Weather Pattern model. All scenarios are located in the directory EXATA_HOME/scenarios/wireless/weather. Table 10-13 lists the sub-directory where each scenario is located.

TABLE 10-13. Weather Pattern Scenarios Included in EXata

Scenario	Description
WeatherExample	To show how to configure the weather model.

A QualNet Terrain Format

This appendix describes the QualNet XML format designed to represent terrain features. The format is specified as an XML schema. This appendix describes this schema as well as additional conventions that are to be followed during the creation of XML files to describe terrain features.

A.1 Overall Description

A.1.1 Terrain Features

Terrain features are an important part of propagation modeling as well as mobility modeling. The XML format described in this appendix can be used as a QualNet standard format to specify terrain feature data relevant to network scenarios. Other terrain feature formats such as ESRI Shapefile and Compact Terrain DataBase (CTDB) can be converted to the QualNet XML format using conversion addon modules available with EXata. (The use of the CTDB terrain format requires the Military Radios Model Library.)

Terrain features currently supported by the format include streets/street segments and intersections, buildings, open enclosures such as parks and stations, and railroads. Clouds, which are related to weather models, are also supported.

A.1.2 Object Hierarchy

A QualNet terrain feature XML file would include terrain features describe within a “Site”. The Site is the area within which all the terrain features for the network scenario are described. A scenario can include multiple terrain feature files but each file cannot describe more that 1000 terrain features. This is further discussed in section A.3.5 on page 456.

All files relevant to a scenario describe terrain feature objects (referred to as “objects” from now on) within the same Site, but each file describes objects in a “Region” independent of Regions specified in other files. So, if a scenario includes two terrain feature files, both files will be described in the context of the same Site, but the objects specified in the first file can be in a different Region of the Site than the objects specified in the second file.

Each Region can contain multiple objects of type Street_Segment, Park, Cloud, Station, Building, Railroad or Intersection. Street_Segments (or Railroads) are described by a list of positions that form the Street Segment (or Railroad). Buildings consist of a set of Building Faces. Parks, Clouds, Building Faces, and Stations are described by the set of positions that describe the area enclosed by the object. Intersections are described by their positions. These objects and their XML format is described in detail in section A.3 on page 451.

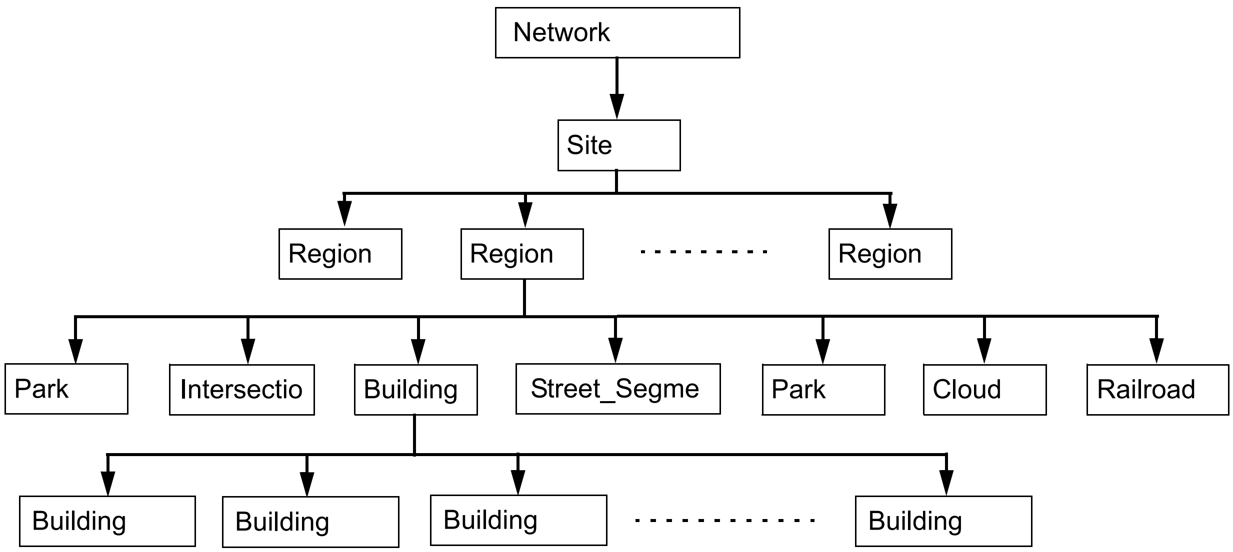

FIGURE A-1. Object Hierarchy

A.2 Coordinate Systems

A.2.1 Specifying Coordinate System Type

The Site object corresponding to each scenario must include the coordinate system type to be used in the file. The coordinate system type specified by the Site object is the global coordinate system type for all objects described in the scenario. This means that unless specified otherwise, all objects in the terrain feature files included in the scenario will describe position/location coordinates in this coordinate system.

Terrain feature objects and region objects can optionally specify a coordinate system type if required. Usually, this will be done if the coordinates of that object are to be described in a coordinate system different than that specified by the Site object.

Currently, the only supported coordinate systems are 3D Cartesian coordinates and WGS-84 geodetic coordinates. Cartesian coordinates are specified as "*x-coordinate y-coordinate z-coordinate*". Geodetic coordinates are specified as "*longitude latitude altitude*".

A.2.2 Specifying Reference Coordinates

The Site object corresponding to each scenario must include the reference coordinates to be used in the terrain feature files. The reference coordinates specified by the Site object are the global reference coordinates for all objects described in the scenario. This means that unless specified otherwise, all objects in the terrain feature files included in the scenario will describe position/location coordinates with reference to these reference coordinates.

Terrain feature objects and region objects can optionally specify reference coordinates if required. Usually, this will be done if the coordinates of that object are to be described with reference to a location different than the reference location specified by the Site object.

All reference coordinates can be specified in WGS-84 geodetic coordinates only.

A.3 Object Description

All objects covered in this section are described in terms of their attributes and the elements included in that object. The elements of an object must occur in the order in which they are described in this section.

A.3.1 Object IDs and References

The Site object, all region objects and all terrain feature objects are uniquely identified by character string IDs that are to be specified by the user. In addition, these objects can also have names. The ID of an object is used to maintain uniqueness of all objects.

Furthermore, it is also used by other objects as a reference. For example, intersections include references to all terrain feature objects that exist at the intersection. So, if three street segments meet at an intersection, the intersection will include the IDs of the three street segments as references to the street segment objects themselves. Since objects can be distributed across multiple files, objects in one file can reference objects in another. But, the user must make sure that all objects referenced by an object must themselves be described in one of the files. No hanging references are allowed.

A.3.2 Site Object

Each terrain format file includes one Site object. The attributes of the Site object must be identical across all terrain format files that pertain to a scenario.

A.3.2.1 Site attributes

Name:	Name of the site (character string). This is an optional attribute.
id:	Site ID (character string). This is a required attribute.
ReferencePoint:	Global reference coordinates specified in geodetic coordinates. This is a required attribute.
CoordinateType:	Global coordinate system type. The possible values are “cartesian” or “geodetic”. This is a required attribute.
totalParts:	Number of files that the terrain features for this site are distributed over. This is a required attribute.
Part:	File number corresponding to the file. This is a required attribute.

A.3.2.2 Site elements

Region Object:	Region specified by the file. This is a required attribute.
Sequence of terrain Feature Objects:	At most 1000 terrain feature objects (described in section 4.5). The different terrain feature objects can be listed in any order.

A.3.3 Base Object Types

All terrain feature objects are based on a set of base object types. Therefore, while the terrain feature objects can be changed by extension or inclusion of the base object types, the primary base objects will not change as they preserve the common elements between various terrain feature types.

refCollection type

This type is meant to hold a set of reference points such as the reference to street segments made by the intersection object.

refCollection type attributes

Name:	Name of the collection (character string). This is an optional attribute.
id:	Object ID (character string). This is a required attribute.

refCollection type elements

reference sequence:	Set of ID references each enclosed in “reference” tags.

A.3.3.1 coordinate3D type

This type is used to specify any position or location coordinates. It is a list of three numbers. The interpretation of these numbers is described in section 3.1.

A.3.3.2 linear type

This type is used to describe any linear terrain features like street segments and railroads. The elements of this type must occur in the order specified below. Note that all linear objects must lie between two objects of the intersection type.

linear type attributes

Name:	Name of the linear object (character string). This is an optional attribute.
id:	Site ID (character string). This is a required attribute.
ReferencePoint:	Global reference coordinates specified in geodetic coordinates. This is an optional attribute.
CoordinateType:	Global coordinate system type. The possible values are “cartesian” or “geodetic”. This is a required attribute.

linear type elements

firstNode:	An object of type coordinate3D with a “objectRef” attribute. This element specifies the location of the first node of the linear object. The objectRef attribute is a reference to the intersection that the firstNode is part of.
node sequence:	An optional sequence of objects of type coordinate3D, each with an optional “objectRef” attribute. A node element specifies the location of any intermediary nodes of the linear object. The optional objectRef attribute is a reference to the intersection that the node may be a part of.
lastNode:	An object of type coordinate3D with a “objectRef” attribute. This element specifies the location of the last node of the linear object. The objectRef attribute is a reference to the intersection that the lastNode is part of.

A.3.3.3 enclosure type

Enclosure type objects are relevant geographical areas in the scenario such as parks, stations. The region object is also an enclosure.

enclosure type attributes

Name:	Name of the linear object (character string). This is an optional attribute.
id:	Site ID (character string). This is a required attribute.
ReferencePoint:	Global reference coordinates specified in geodetic coordinates. It is optional.
CoordinateType:	Global coordinate system type. The possible values are “cartesian” or “geodetic”. This is a required attribute.

enclosure type elements

position sequence:	A sequence of at least three objects of type coordinate3D, each with an optional exitIntersectionID attribute. A position object signifies the coordinates of a single vertex of the two dimensional structure. The sequence of positions make up the structure. The exitIntersectionID is a reference to the intersection the enclosure may be a part of.
representative sequence:	A sequence of objects of type coordinate3D. It indicates the position of a representative (such as station or park information booth) at the enclosure.

A.3.3.4 intersection type

This is the base object for street intersections.

intersection type attributes

Name:	Name of the linear object (character string). This is an optional attribute.
id:	Site ID (character string). This is a required attribute.
ReferencePoint:	Global reference coordinates specified in geodetic coordinates. This is an optional attribute.
CoordinateType:	Global coordinate system type. The possible values are “cartesian” or “geodetic”. This is a required attribute.

intersection type elements

location:	An object type coordinate3D. It indicates the location of the intersection.
synchronized signals sequence:	A sequence of objects of type refCollection. Each synchronizedSignals object includes references to a subset of the IDs of street segments that meet at that intersection. The subset of street segments that are referenced by a synchronizedSignals object are the street segments for which the traffic signals are synchronized.
objects:	An object of type refCollection. This is the list of ID references to all the objects that meet at the intersection.

A.3.3.5 structure2D type

This object type is used to describe two-dimensional structures. This includes building faces and clouds.

structure2D type attributes

Name:	Name of the structure2D object (character string). This is an optional attribute.
id:	Site ID (character string). This is a required attribute.
ReferencePoint:	Global reference coordinates specified in geodetic coordinates. This is an optional attribute.
CoordinateType:	Global coordinate system type. The possible values are “cartesian” or “geodetic”. This is a required attribute.

structure2D type elements

position sequence:	A sequence of at least three objects of type coordinate3D. A position object signifies the coordinates of a single vertex of the two dimensional structure. The sequence of positions makeup the structure.
thickness:	A decimal value indicating the thickness of the structure.

A.3.3.6 structure3D type

This object type is used to describe three-dimensional structures. This includes buildings.

structure3D type attributes

Name:	Name of the structure3D object (character string). This is an optional attribute.
id:	Site ID (character string). This is a required attribute.
ReferencePoint:	Global reference coordinates specified in geodetic coordinates. This is an optional attribute.
CoordinateType:	Global coordinate system type. The possible values are “cartesian” or “geodetic”. This is a required attribute.

Structure3D type elements

face sequence:	A sequence of at least four objects of type structure2D. Each face is a facet of the three dimensional structure. In the case of a building the faces would be the outside walls and the roof.

A.3.3.7 points type

This object type is used to describe any collection of points, indicating a collection of locations or positions in the scenario.

points type attributes

Name:	Name of the points object. It is an optional character string.
id:	Site ID (character string). This is a required attribute.
ReferencePoint:	Global reference coordinates specified in geodetic coordinates. This is an optional attribute.
CoordinateType:	Global coordinate system type. The possible values are “cartesian” or “geodetic”. This is a required attribute.

points type elements

point sequence:	Sequence of at objects of type coordinate3D.

A.3.4 Region Object

Each file includes a distinct region object within which all the terrain features described in the file lie. It is an object of type enclosure (see section A.3.3.3 on page 454.)

A.3.5 Terrain Feature Objects

A.3.5.1 Street_Segment object

This is an object of type linear.

A.3.5.2 Park object

This is an object of type enclosure.

A.3.5.3 Cloud object

This is an object of type structure2D.

A.3.5.4 Station object

This is an object of type enclosure.

A.3.5.5 Building object

This is an object of type structure3D. In addition, the position elements of the building faces must be specified in the order they appear when traversed counter-clockwise around the outward pointing normal of the face.

A.3.5.6 Railroad object

This is an object of type linear.

A.3.5.7 Intersection object

This is an object of type intersection. Note that the objects elements could include references to parks, stations, buildings or any other terrain feature objects.

A.3.6 Distribution of Objects

In the interest of performance of the XML file parsing tool to be used load the terrain feature objects into the simulator, each file is allowed to include at most 1000 terrain feature objects. But each scenario can include multiple terrain feature files.

A.4 Example Terrain Features File

An example terrain features file is shown below.

```
<?xml version="1.0"?>
<Site Name="test" id="Site1" ReferencePoint="0.0 0.0 0.0"
CoordinateType="cartesian" part="1" totalParts="01" xmlns:xsi="http://
www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="file:qualnet-road.xsd">
<Region id="Region0" CoordinateType="cartesian">
<position>0.000000 0.000000 0.000000</position>
</Region>
<Building id="ID1" Name="volume">
<face Name="wall" id="ID2">
<position>1.0 2.0 0.0</position>
<position>1.0 1.0 0.0</position>
<position>1.0 1.0 1.0</position>
<position>1.0 2.0 1.0</position>
</face>
...
<face Name="wall" id="ID5">
<position>1.0 1.0 0.0</position>
<position>2.0 1.0 0.0</position>
<position>2.0 1.0 1.0</position>
<position>1.0 1.0 1.0</position>
</face><face Name="roof" id="ID6">
<position>1.0 1.0 1.0</position>
<position>2.0 1.0 1.0</position>
<position>2.0 2.0 1.0</position>
<position>1.0 2.0 1.0</position>
</face>
</Building>
<Building id="ID7" Name="volumeTwo">
<face Name="wall" id="ID8">
<position>1.0 4.0 0.0</position>
<position>1.0 3.0 0.0</position>
<position>1.0 3.0 1.0</position>
<position>1.0 4.0 1.0</position>
</face>
...
<face Name="wall" id="ID11">
<position>1.0 3.0 0.0</position>
<position>2.0 3.0 0.0</position>
<position>2.0 3.0 1.0</position>
<position>1.0 3.0 1.0</position>
</face>
<face Name="roof" id="ID12">
<position>1.0 3.0 1.0</position>
<position>2.0 3.0 1.0</position>
<position>2.0 4.0 1.0</position>
```

```
<position>1.0 4.0 1.0</position>
</face>
</Building>
</Site>
```

A.5 Assumptions, Dependencies and Anticipated Future Changes

The terrain feature format is still in design. Therefore, the base objects, terrain feature objects or the entire hierarchy can be modified to cater to scenarios. Moreover, addition of new objects and object types is greatly anticipated.