Qualnet Tutorial

Scalable Network Technologies

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QualNet Training Workshop

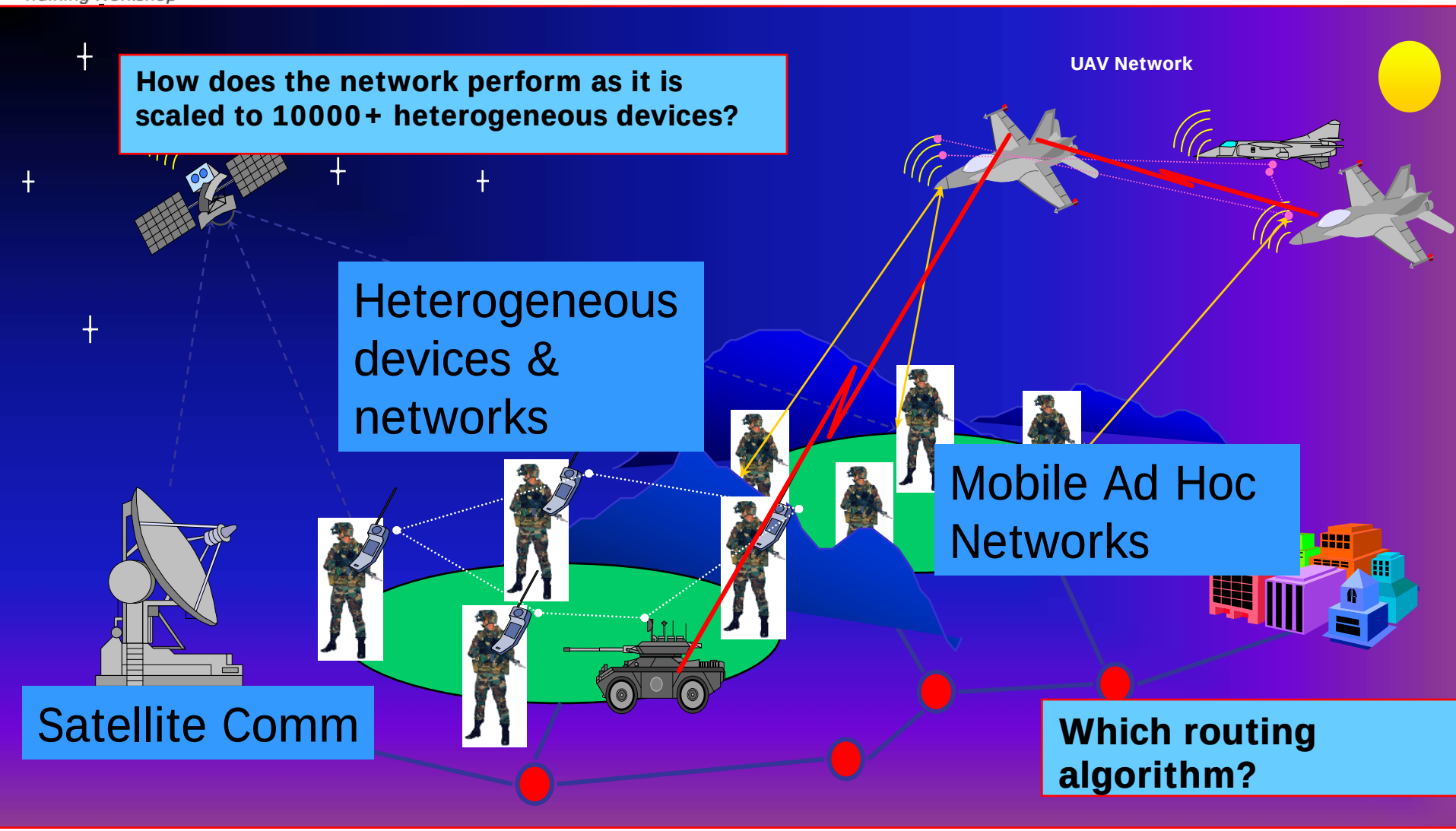
Outline

- QualNet Overview: slides 3-10
- Installation: slides 11-16
- Simulation Architecture: slides 17-20
- Wireless Experiment Design (both command line and GUI): slides 21-46
- Animator Execution (demo): slides 47-52
- Analyzer: slides 53-59
- Resources: slide 60

Advantages of QualNet

- Rapid prototyping of protocols
- Comparative performance evaluation of alternative protocols at each layer
- Built-in measurements on each layer
- Modular, layered stack design
- Standard API for composition of protocols across different layers
- Scalability via support for parallel execution
- GUI Tools for system/protocol modeling

Genesis: GloMoSim, DARPA funded effort at UCLA ('97 – '00) for efficient simulation of large heterogeneous networks



DARPA Objective: Large Heterogeneous Network Simulation

QualNet

- Commercial derivative of GloMoSim
- Substantially expanded MANET models:
  - AODV, DSR, OLSR, 802.11 DCF, 802.11 PCF, 802.11a, directional antennas, ...
  - Rapid GUI-based model design, animation & analysis
  - High-fidelity commercial protocol & device models
- Analysis:
  - Comparative performance evaluation of alternative protocols at each layer
  - Built-in measurements on each layer
- Modular, layered stack design
- Scalability via support for parallel execution

QualNet Versatility

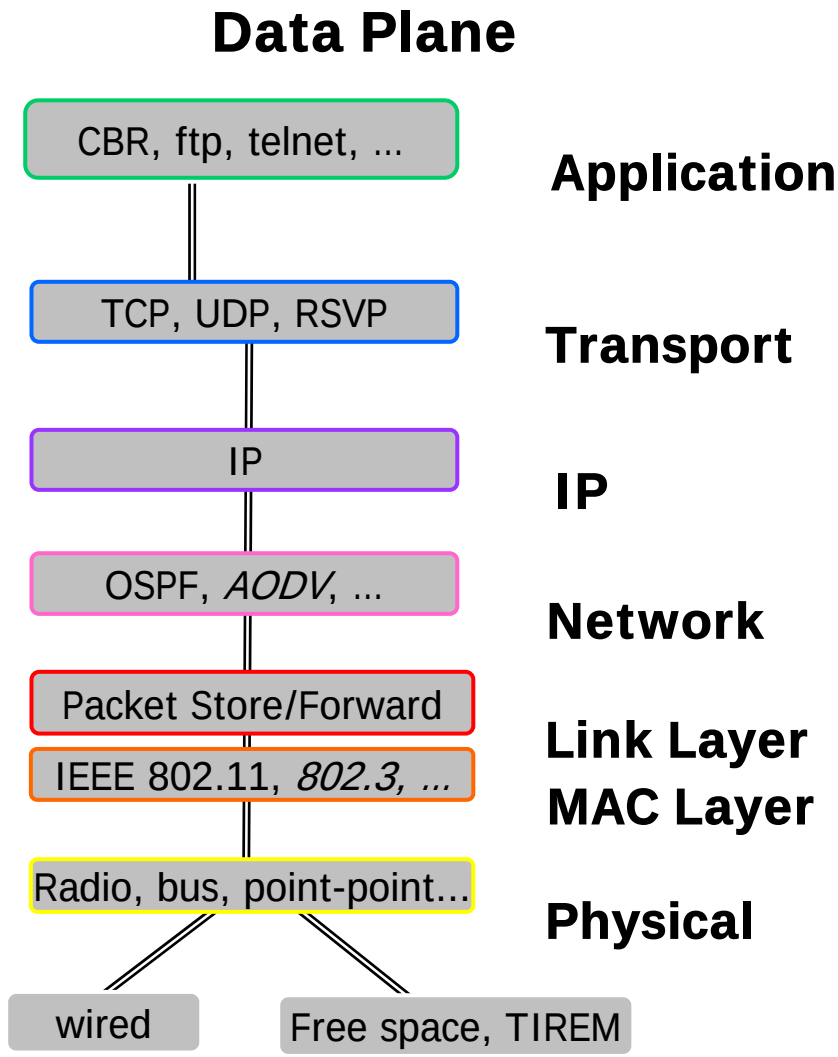
- GloMoSim was designed for MANET
- QualNet supports a wider range of networks and analysis
  - MANET
  - QoS
  - Wired Networks
  - Satellite
  - Cellular
- This presentation focuses on QualNet's MANET features

QualNet Model Library

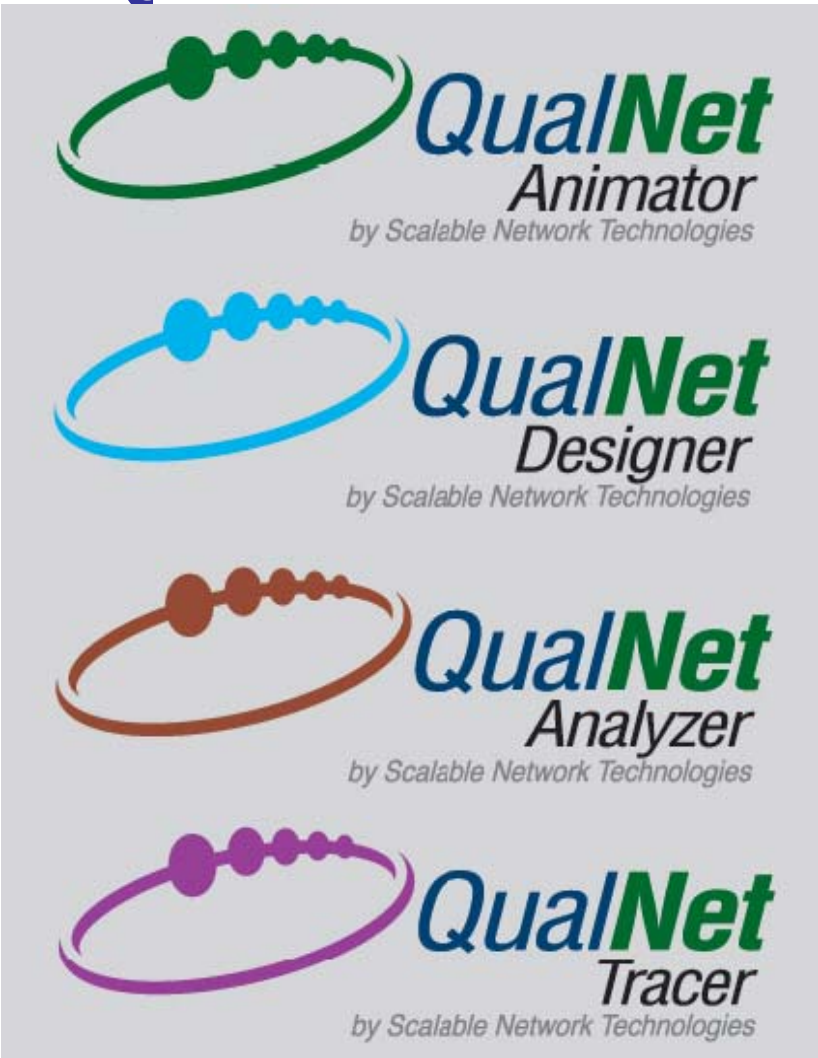
- MANET
  - 802.11a, 802.11b, CSMA, MACA, AODV, DSR, LAR1, STAR, ODMRP, ZRP, FSR, OLSR, directional antenna
- QoS
  - WFQ, WRR, SCFQ, CBQ, QoSPF, diffserv, RED, RIO, WRED, RSVP-TE
- Wired Networks
  - OSPF, BGP, router configuration, IGRP, EIGRP, HSRP, import of LAN configuration
- Satellite
  - Geo-stationary
- Cellular
  - GSM

QualNet Layer Model

- Uses an architecture that is similar to one used in physical networks with well-defined APIs between neighboring layers
- Provides capability for network emulation by supporting direct code migration between the model and operational networks.
- Protocols interface with a well-defined API defining interactions between layers immediately above and below its own
- The unit defining the interaction is the *Message*, which is generally either a *Packet* or a *Timer*



QualNet Developer Toolkit



- Animator: Graphical experiment set up & animation tool
- Designer: Graphical, finite state machine-based custom protocol design tool
- Analyzer: Statistical graphing tool for built-in and custom statistics collection
- Tracer: Packet level tracing & visualization tool.

QualNet Directory Structure

- /addons optional packages
- /application application layer protocols and traffic generators
- /bin executable and configuration or input/output files
- /data storage for sample files, e.g. modulation and terrain
- /gui the Graphical User Interface (GUI)
- /include common include files
- /mac code for the mac layer protocols
- /main the basic design framework/Makefiles
- /mobility the code for mobility models
- /network code for the network layer and routing protocols
- /phy wireless physical and propagation models
- /tcplib trace based TCP applications (FTP, TELNET, HTTP)
- /transport transport layer protocols (TCP/UDP)
- /verification Sample files and outputs

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Installation

- Prerequisites
  - C Compiler
    - Visual C++ 6.0 w/ SP5 on Windows
      - Must be configured to run from the command line.
    - gcc on Unix
  - Java version 1.3.
  - A QualNet license.

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Program Environment

- Define QUALNET_HOME and add GUI and path
- On Unix (assuming csh or tcsh), add to .cshrc
  - setenv QUALNET_HOME ~/qualnet/3.6
  - set path=($path ~/qualnet/3.6/gui/bin)
- On Windows
  - Right-click **My Computer**, choose **Properties**
  - Choose **Advanced** → **Environment Variables**
  - Add QUALNET_HOME with value C:\qualnet\3.6
  - Edit Path: add C:\qualnet\3.6\gui\bin
  - Click **OK**.

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Compilation

- On Windows
  - cd %QUALNET_HOME%\main
  - copy Makefile-windowsnt Makefile
  - nmake
- On unix
  - cd $QUALNET_HOME/main
  - make -f Makefile-<osname>-<compiler>
  - (e.g. on Linux, make -f Makefile-linux-gcc-2.95)

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Trial Run

- Run the default experiment
  - cd C:\qualnet\3.6\bin
  - qualnet default.config
- Examine the output
  - more default.stat

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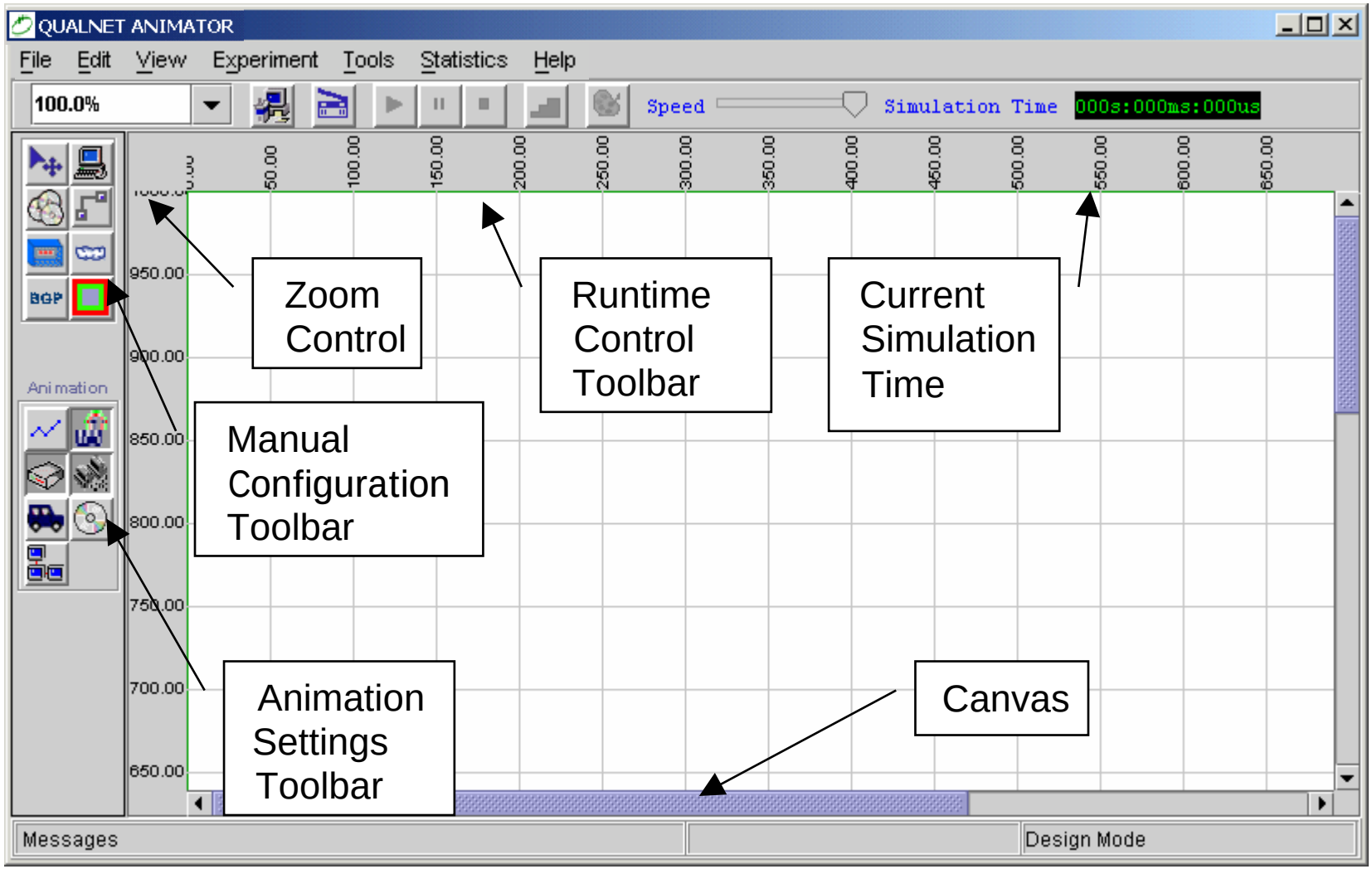
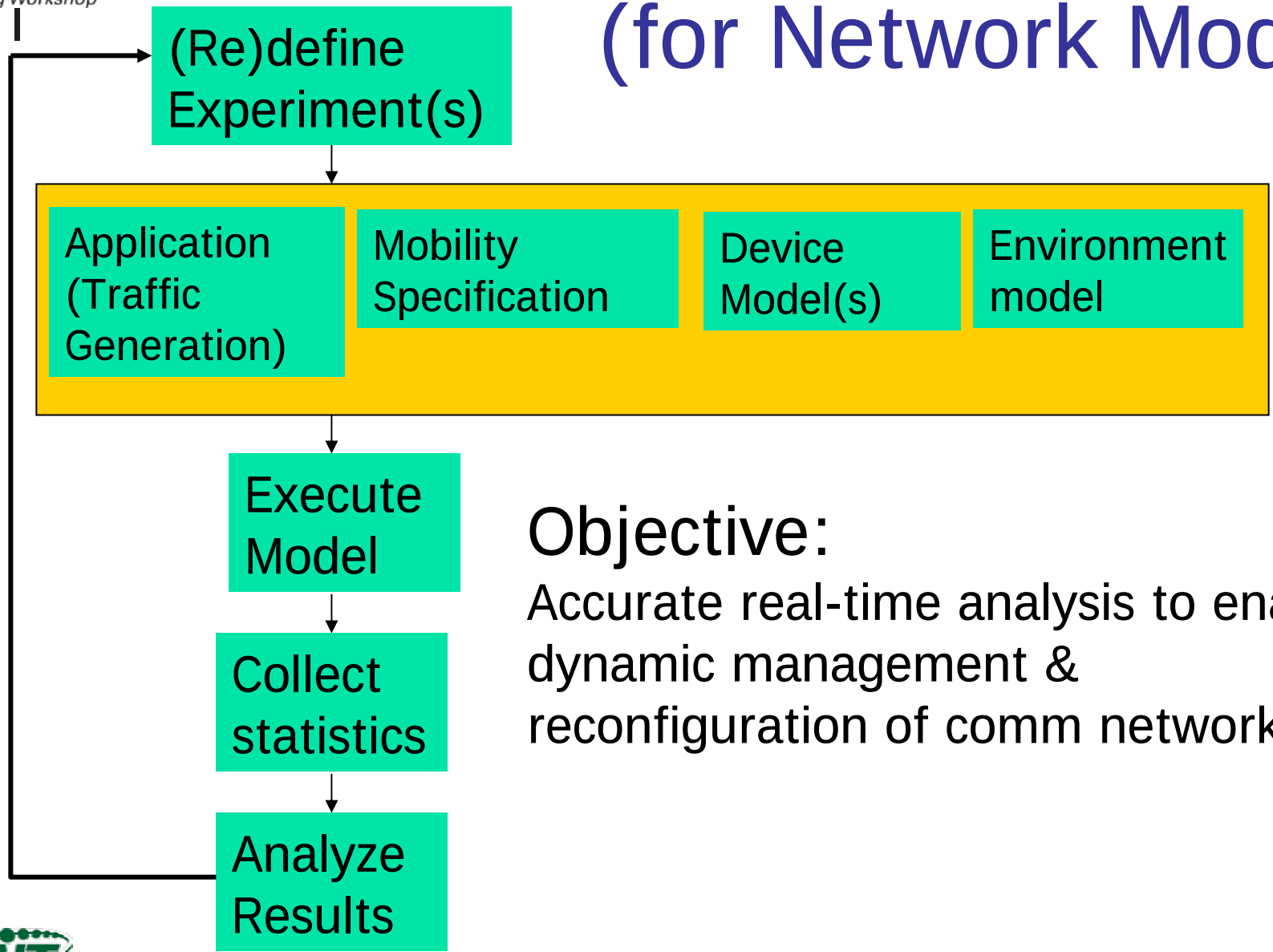
Animator

- Start Animator by doing one of the following:
  - From a Command Prompt, type **RunQualnet**
  - Or … Click **QualNet** icon on desktop
- Press **Setup QualNet Parameters**
- Go to **Wireless Settings** tab

Animator Layout



Simulation Study Life Cycle (for Network Models)



Objective:

Accurate real-time analysis to enable dynamic management & reconfiguration of comm networks

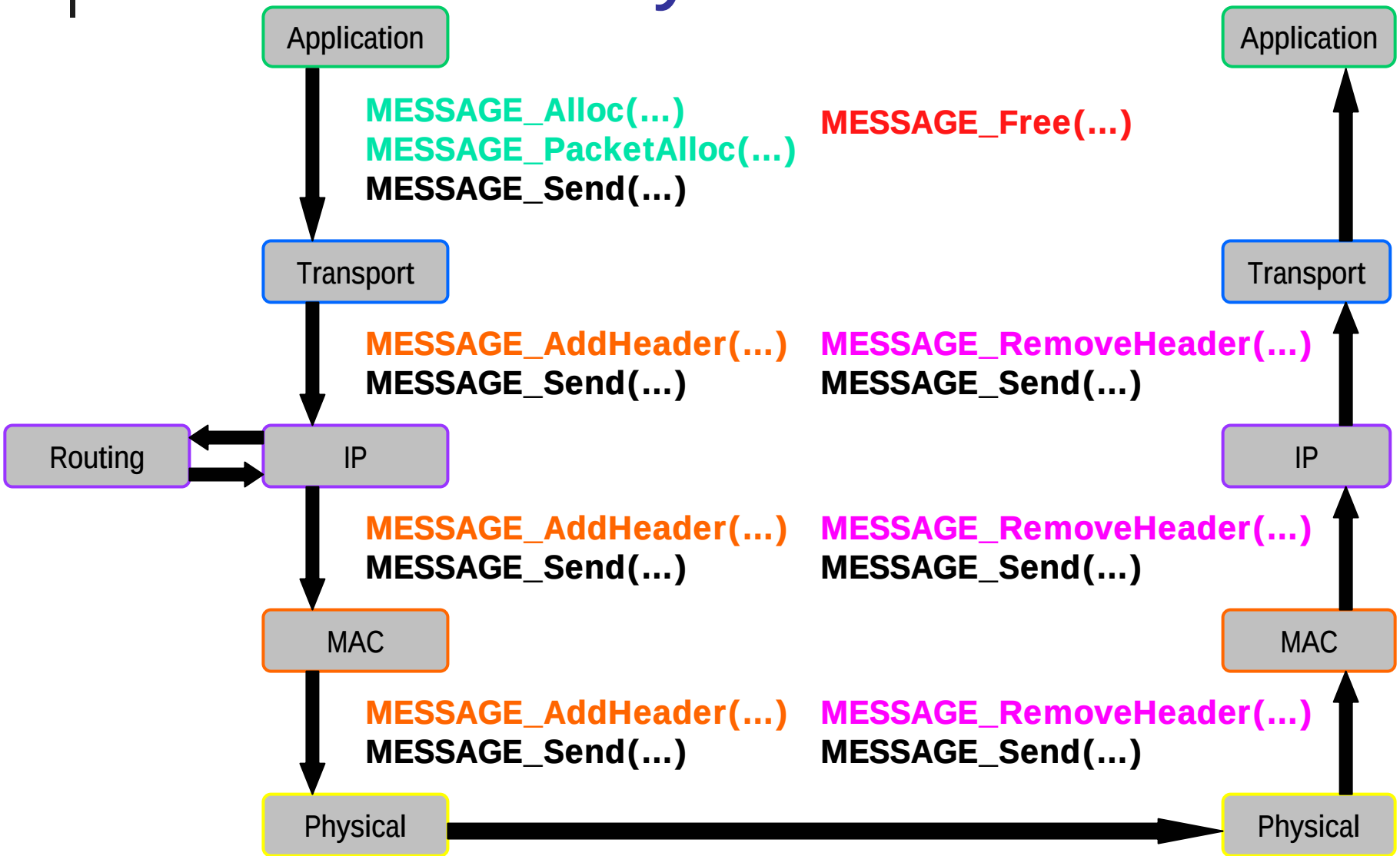
Simulation Experiment Life Cycle

- Startup
  - Read Input Files
  - Initialize Wireless Environment
  - Create/Initialize Nodes
- Execution
  - Check for External Inputs (via HLA, etc.)
  - Execute Events
- Shut down
  - Finalize Nodes
  - Produce Output Files

Node Life Cycle

- Initialization
  - Bottom up layer initialization
  - Read Input Files
- Event Handling
  - Creation
  - Scheduling
  - Handling
- Finalization
  - Printing Statistics

Packet Life Cycle



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Experiment Design & Analysis

- Setting Global Variables
  - Simulation time & seed, coordinate system, terrain
  - Layer/Protocol related parameters:
    - Channel/Radio
    - Physical Layer
    - MAC Layer
    - Network Layer
- Node placement & mobility
- Specifying topology and configuring networks
- Adding Traffic
  - Application setup
- Running & Analyzing

Configuration Files

- Line entry format:

  [Qualifier] <PARAMETER>[Index] <VALUE>

  - Qualifier (optional) specifies a range of nodes and has precedence over the general one
  - Similarly, the optional Index specifies an array of parameters, such as priority queues.
  - E.g.

```
MOBILITY NONE
[5 thru 10] MOBILITY RANDOM-WAYPOINT
```

- Notes:
  - Some settings require additional parameters, e.g. MOBILITY
  - Lines starting with # are treated as comments

Qualifiers and Indices

- Global Qualifier

```
MOBILITY  NONE
```

- Subnet Qualifier

```
[N8-2.0] MAC-PROTOCOL  MACA
```

- Node Qualifier

```
[5 thru 15] MOBILITY NONE
```

- Index for an array of 3 priority queues

```
QUEUE-WEIGHT[0] 0.5
QUEUE-WEIGHT[1] 0.3
QUEUE-WEIGHT[2] 0.2
```

Other Configuration Files

- Node placement: **NODE-PLACEMENT-FILE**
  - → See details in **bin/default.nodes**
- Mobility trace: **MOBILITY-TRACE-FILE**
  - → See details in **bin/default.mobility**
- Static routing: **STATIC-ROUTE-FILE**
  - → See details in **bin/default.routes-static**
- Link/node faults: **FAULT-CONFIG-FILE**
  - → See details in **bin/default.fault**
- Multicast membership: **MULTICAST-GROUP-FILE**
  - → See details in **bin/default.member**

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Important Global Variables

- EXPERIMENT-NAME: Name of the output statistic file
  e.g. **`EXPERIMENT-NAME  default`**
  Resulting statistics are written in **`default.stat`**
- SIMULATION-TIME: The length of time to simulate.
  e.g. **`SIMULATION-TIME  15M`**
  (Available time units: NS, US, MS, S, M, H, D; default is in seconds)
- SEED: The random seed used to derive all other seeds used in the simulation.
  e.g. **`SEED  1`**

Coordinates and Terrain Dimensions

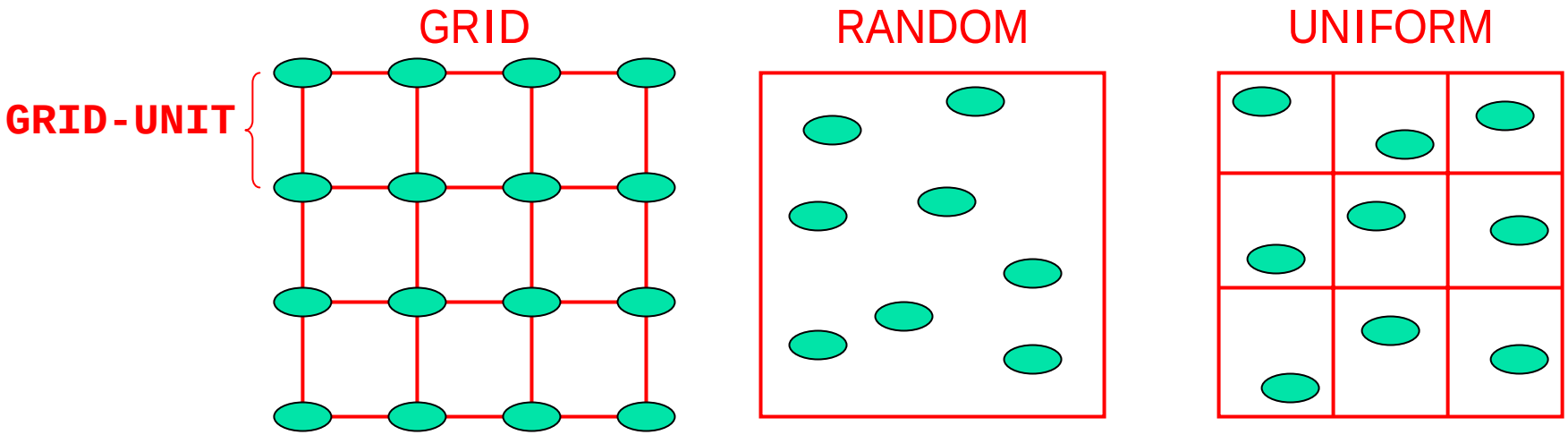
- COORDINATE-SYSTEM: LATLONALT or CARTESIAN
  e.g., **COORDINATE-SYSTEM CARTESIAN**
- TERRAIN-DIMENSIONS: The size of the rectangular area to simulate (in meters) for Cartesian coordinate.
  e.g., **TERRAIN-DIMENSIONS (1000, 1000)**
- Terrain corners are required by LATLONALT system
  e.g., **TERRAIN-SOUTH-WEST-CORNER (30.00, 40.00)**
  TERRAIN-NORTH-EAST-CORNER (30.01, 40.01)
- Irregular terrain

```
TERRAIN-DATA-TYPE DEM
DEM-FILENAME[0] ../data/terrain/los_angeles-w
DEM-FIlENAME[1] ../data/terrain/los_angeles-e

# Tie nodes to the ground level
MOBILITY-GROUND-NODE YES
```

Node Placement

- NODE-PLACEMENT: GRID, RANDOM, UNIFORM, FILE



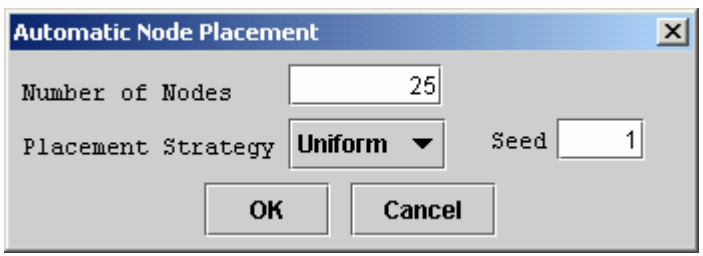
- Use FILE to specify node positions in a file

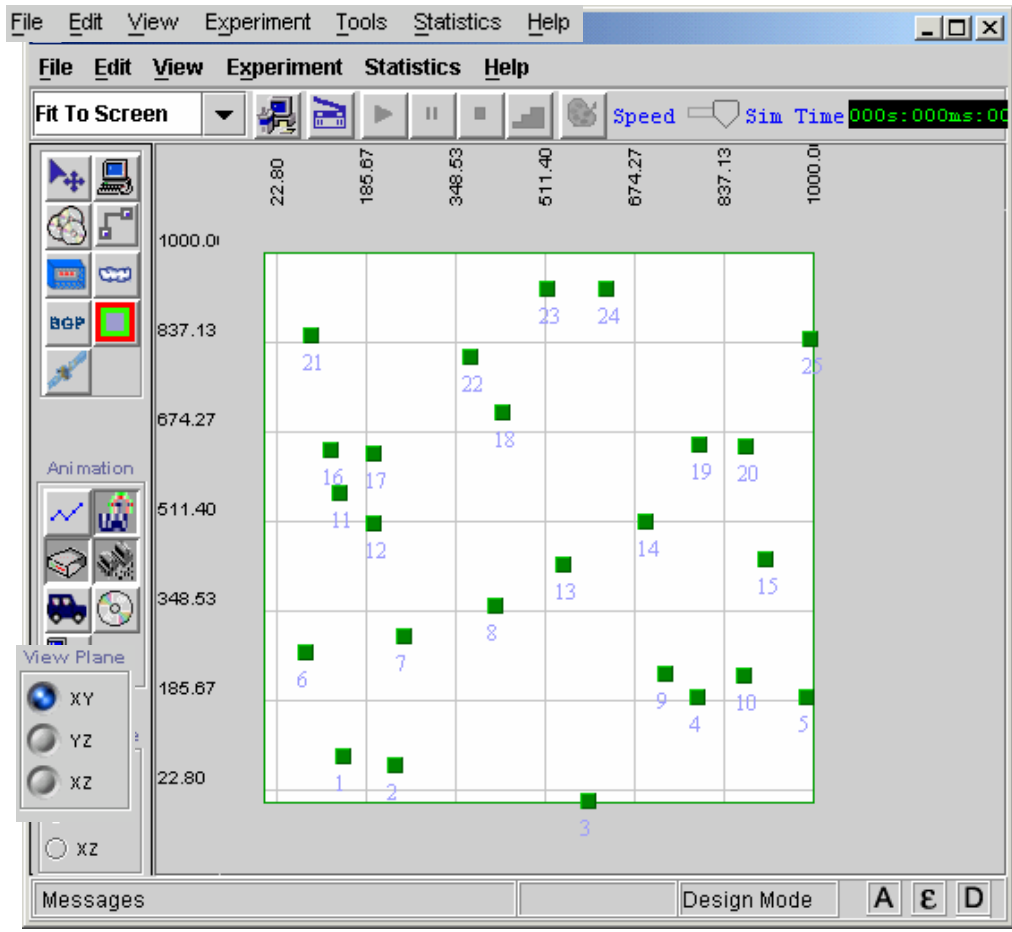
```
NODE-PLACEMENT      FILE
NODE-PLACEMENT-FILE ./default.nodes
```

  - Format: *nodeId 0 (x, y, z) [azimuth elevation]*

Node Placement In GUI

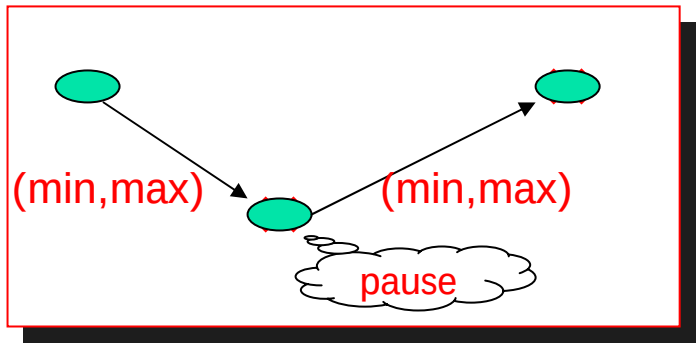
- Manual
  - Choose Device type and place
- Automatic
  - Experiment->Automatic Node Placement
  - Choices of Uniform, Random or Grid



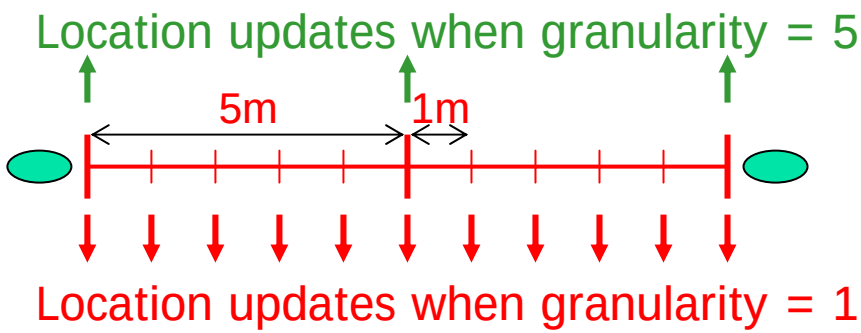


Mobility Model

- NONE, TRACE
- RANDOM-WAYPOINT
  - e.g. **MOBILITY RANDOM-WAYPOINT**
    MOBILITY-WP-PAUSE 30S
    MOBILITY-WP-MIN-SPEED 0
    MOBILITY-WP-MAX-SPEED 10



- MOBILITY-POSITION-GRANULARITY: distance in meters at which a node's location is updated
  - ☞ small values potentially slow down the simulation



Setting Up A Wireless Scenario (1)

- Scenario Description
  - Two small subnets communicating on different frequencies, 2.4GHz and 2.5GHz
  - Mostly default settings: 802.11b, AODV, Two-Ray...
  - 5 nodes in the scenario
    - each within 300m of at least one other node
    - 3 in each subnet, one in both
  - Two subnets
    - One with Listening/Listenable Mask = 01, the other set to 10.
  - One CBR application between two distant nodes

Specifying Topology

- SUBNET Parameter
  - SUBNET <subnet> { comma-delimited list of nodes }
- Ex. **`SUBNET N8-1.0 { 1, 3, 7 thru 9 }`**
  - NodeIds 1, 3, 7, 8, and 9 have network interfaces with address 0.0.1.1 through 0.0.1.5

Node ID	Interface Address
1	0.0.1.1
3	0.0.1.2
7	0.0.1.3
8	0.0.1.4
9	0.0.1.5

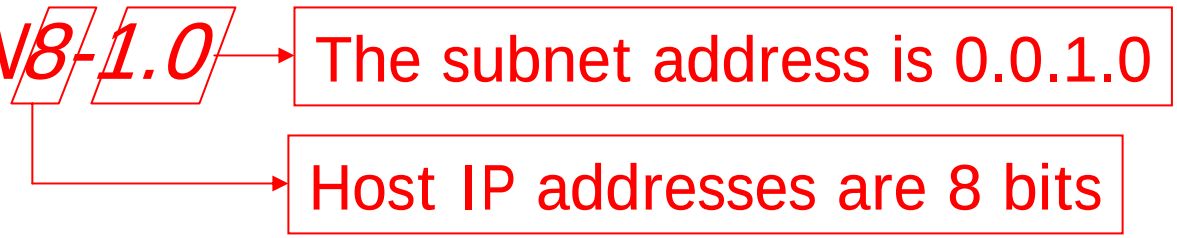
- Basic form: **`SUBNET N16-0 { 1 thru n }`**
  - *n* is the number of nodes
  - IP address and Node ID are identical
    → Node 5 has IP address 0.0.0.5

Subnet Shorthand

- Format:

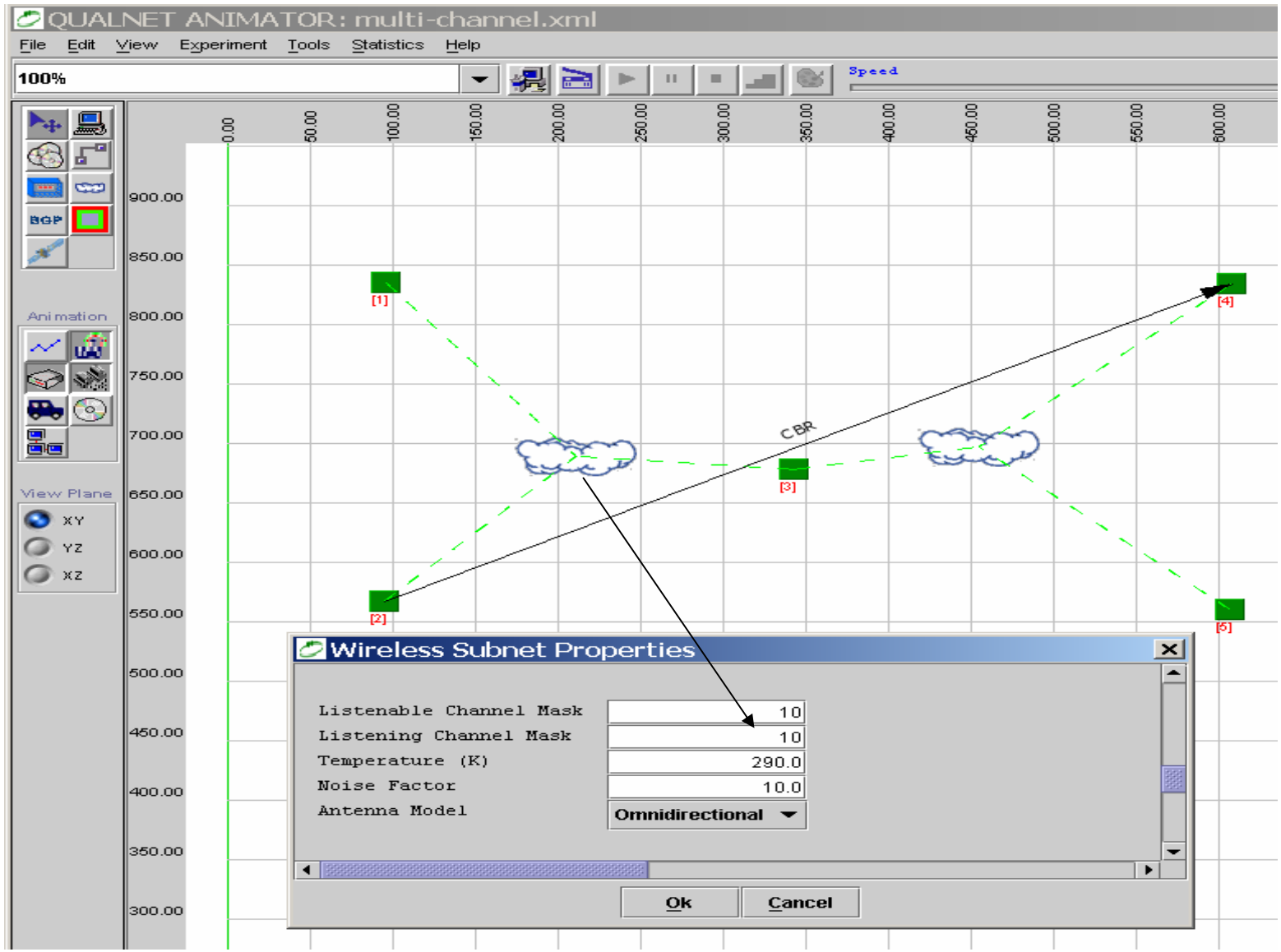
  N<# host bits>**-**<address with front end 0's omitted>

- Ex. *N8-1.0*



  - This allows for 2^8-2 (254) hosts in this subnet with IP addresses numbered from 0.0.1.1 through 0.0.1.254
  - The broadcast address for this subnet is 0.0.1.255
  - The subnet mask is 255.255.255.0
  - *N8-0.0.1.0* is an equivalent representation

Wireless Scenario Layout in Animator



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Command Line Layout

SUBNET N3-1.0 {1, 2, 3}

[N3-1.0] CHANNEL-LISTENABLE-MASK 10

[N3-1.0] CHANNEL-LISTENING-MASK 10

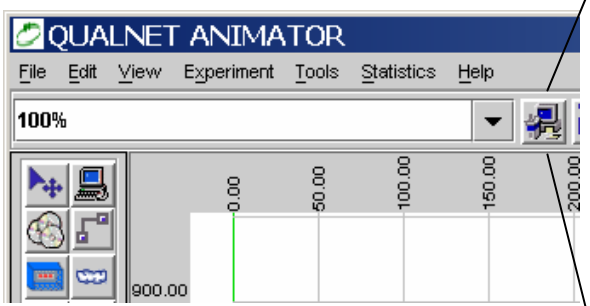
SUBNET N3-2.0 {3 thru 5}

[N3-2.0] CHANNEL-LISTENABLE-MASK 01

[N3-2.0] CHANNEL-LISTENING-MASK 01

Wireless Settings in Animator

Open Global Parameters



Global Parameters

File

General | Node Positioning | Wireless Settings | Network Protocols | Traffic and Status | Statistics | Node Specific

Channel

Channel Frequency 0	2.4	GHz	Add Another	Remove One
Channel Frequency 1	2.4	GHz		
Propagation Model 0	Statistical			
Propagation Model 1	Statistical			
Propagation limit (dBm) 0	-111.0			
Propagation limit (dBm) 1	-111.0			
Pathloss model 0	Free space			
Pathloss model 1	Two Ray			
Shadowing Sigma (dB) 0	0.0			
Shadowing Sigma (dB) 1	0.0			
Fading Model 0	Rayleigh	Fading Gaussian Components File	Please Specify	Browse... Reset
		Fading Max Velocity	10.0	
Fading Model 1	Ricean	Ricean K Factor 1	0.0	
		Fading Gaussian Components File 1	Please Specify	Browse... Reset
		Fading Max Velocity 1	10.0	

Save Close

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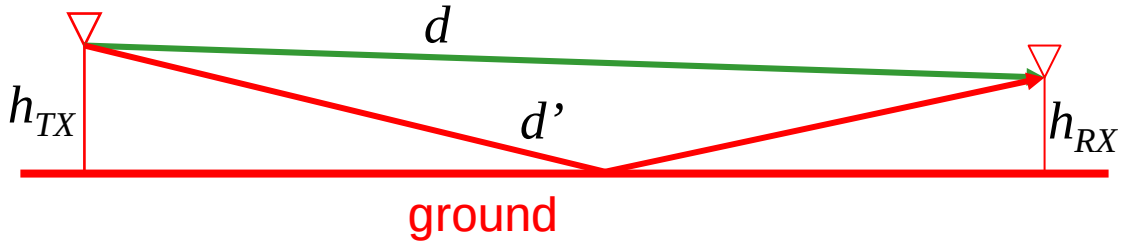
Channel Properties

- Channel Frequencies
  - PROPAGATION-CHANNEL-FREQUENCY[0] 2.4e9
  - PROPAGATION-CHANNEL-FREQUENCY[1] 2.5e9
- For each frequency you can set
  - Statistical Propagation model
  - Pathloss model
    - Free space or two ray or ITM
  - Fading model
    - Rayleigh
    - Ricean

Propagation Model

- PROPAGATION-LIMIT: received signals with power below this limit (in dBm) will not be processed.
  e.g. **`PROPAGATION-LIMIT  -111.0`**
- PROPAGATION-PATHLOSS-MODEL: specifies path-loss model
  - FREE-SPACE → Empty space, no ground (r^2 loss)
  - TWO-RAY → Flat ground (r^4 loss for far sight)
    - Considers a ray bounced back from the ground

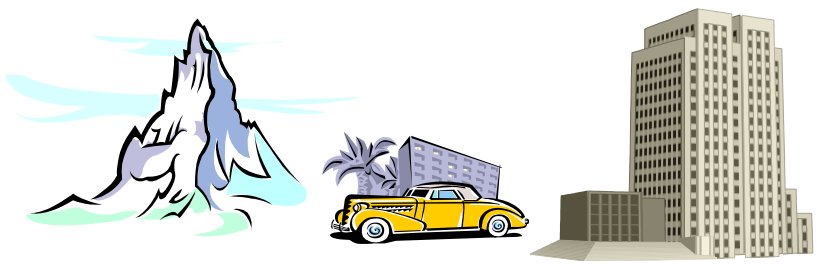


  - ITM → Irregular terrain (terrain database required)

Fading Model

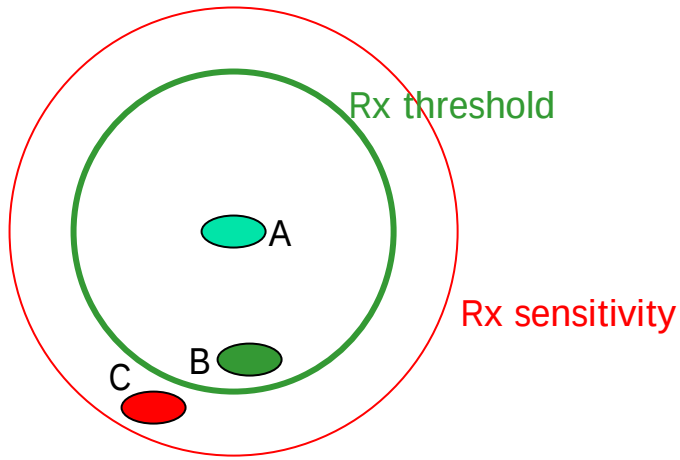
- Applied to only narrowband channels (flat fading)
- Specified by PROPAGATION-FADING-MODEL
- Available models
  - NONE – No fading
  - RAYLEIGH – Highly mobile, no line of sight
  - RICEAN – requires an additional parameter RICEAN-K-FACTOR
    - K = 0 : no line of sight (similar to RAYLEIGH)
    - K = ∞ : strong line of sight

e.g. **PROPAGATION-FADING-MODEL RAYLEIGH**



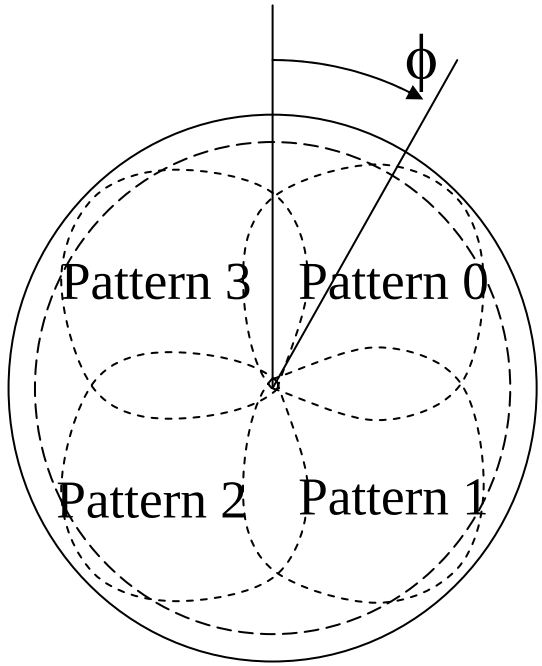
Physical Layer (Radio) Model

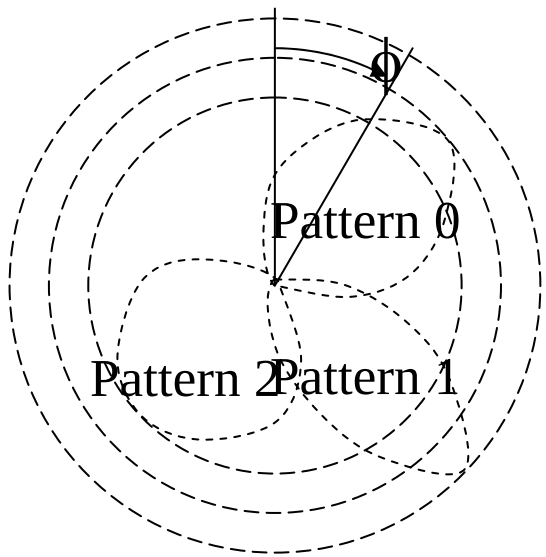
- Noise modeling
  - Thermal noise
    - PHY-NOISE-FACTOR (default 10)
    - PHY-TEMPERATURE (in K; default 290)
  - Interference
    - PHY-RX-MODEL (SNR-THRESHOLD-BASED | BER-BASED)
- Parameters specific to 802.11b
  - PHY802.11b-DATA-RATE (in bps)
  - PHY802.11b-TX-POWER (in dBm)
  - PHY802.11b-RX-SENSITIVITY (in dBm)
  - PHY802.11b-RX-THRESHOLD (in dBm)



Antenna Models

- Omnidirectional
- Switched beam (same shape, different angle)
  - ANTENNA-MODEL SWITCHED-BEAM
  - ANTENNA-AZIMUTH-PATTERN-FILE default.antenna-azimuth
- Steerable (different shape, different angle)
  - ANTENNA-MODEL STEERABLE
  - ANTENNA-AZIMUTH-PATTERN-FILE steerable.antenna-azimuth





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Routing Protocols

- Proactive protocols
  - BELLMANFORD
  - RIPv2
  - OSPFv2
  - OLSR
- Reactive protocols
  - AODV
  - DSR
  - LAR1
- Static routing: requires STATIC-ROUTE-FILE

MAC Layer Model

- MAC-PROTOCOL: specifies MAC layer protocol
  - CSMA
    - Requires carrier sensing before transmission
    - If the channel is free, the packet is transmitted immediately
    - Otherwise, set a random timeout
  - MACA
    - Uses RTS/CTS to acquire channel
    - Does not carrier sense
  - MAC802.11
    - CSMA/CA with ACKs and optional RTS/CTS
  - TDMA
  - MAC802.3/SWITCHED-ETHERNET → Wired networks
  - SATCOM → Satellite networks
- PROMISCUOUS-MODE: set to YES to allow nodes to overhear packets destined to the neighboring node (required by DSR).

Network Layer: IP

- Currently the only support network layer protocol
- Available queuing models
  - First-in first-out (FIFO)
  - Variations of Random Early Detection: RED, RIO, WRED,
- Three priority types supported: *control* (0), *real-time* (1), and *non-real-time* (2)
- IP-QUEUE-PRIORITY-QUEUE-SIZE specifies the queue's size (in bytes)
  - Each priority queue's size can be specified separately

```
IP-QUEUE-PRIORITY-QUEUE-SIZE[0] 25000
IP-QUEUE-PRIORITY-QUEUE-SIZE[1] 50000
IP-QUEUE-PRIORITY-QUEUE-SIZE[2] 50000
```

Application Specification

- APP-CONFIG-FILE: Specifies a file with a list of apps/traffic generators to run.
  - FTP
  - TELNET
  - CBR/MCBR
  - HTTP
  - VoIP
  - *etc*
- See bin/default.app for more details

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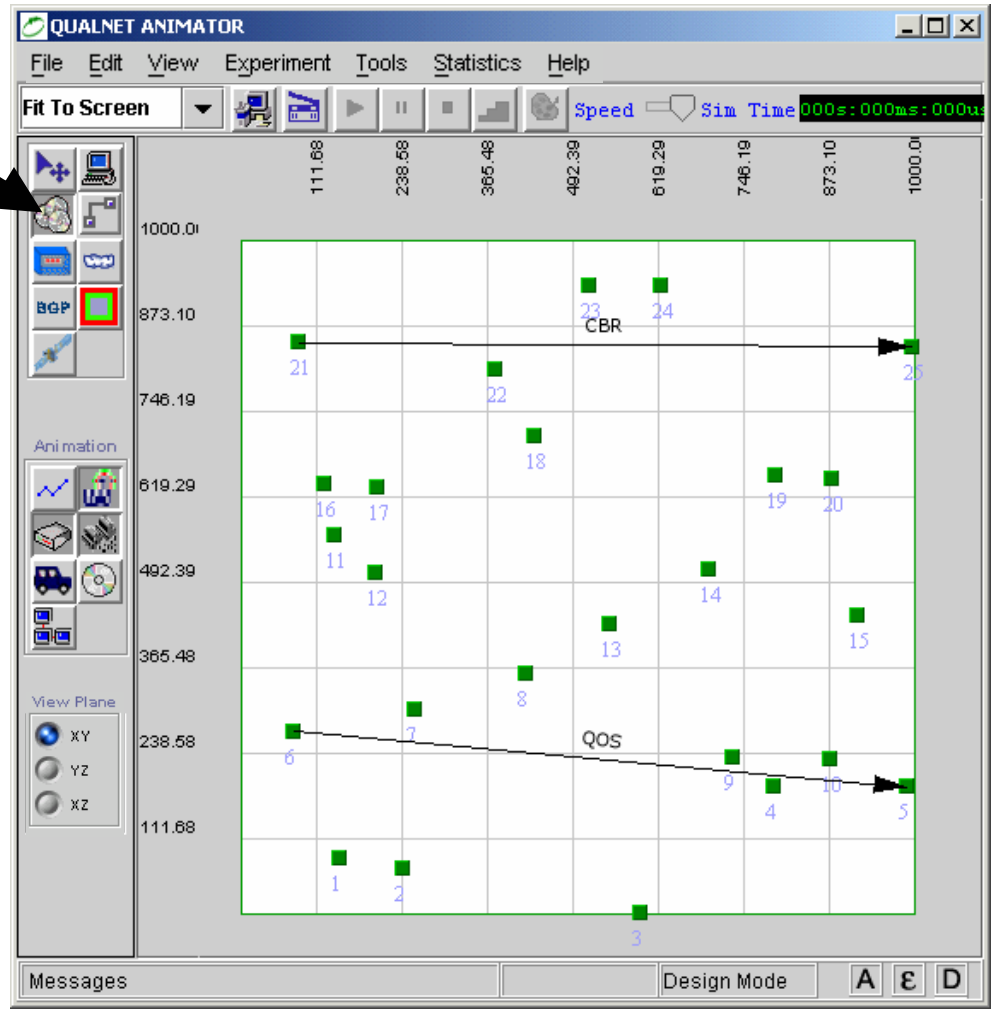
Application Specification In GUI

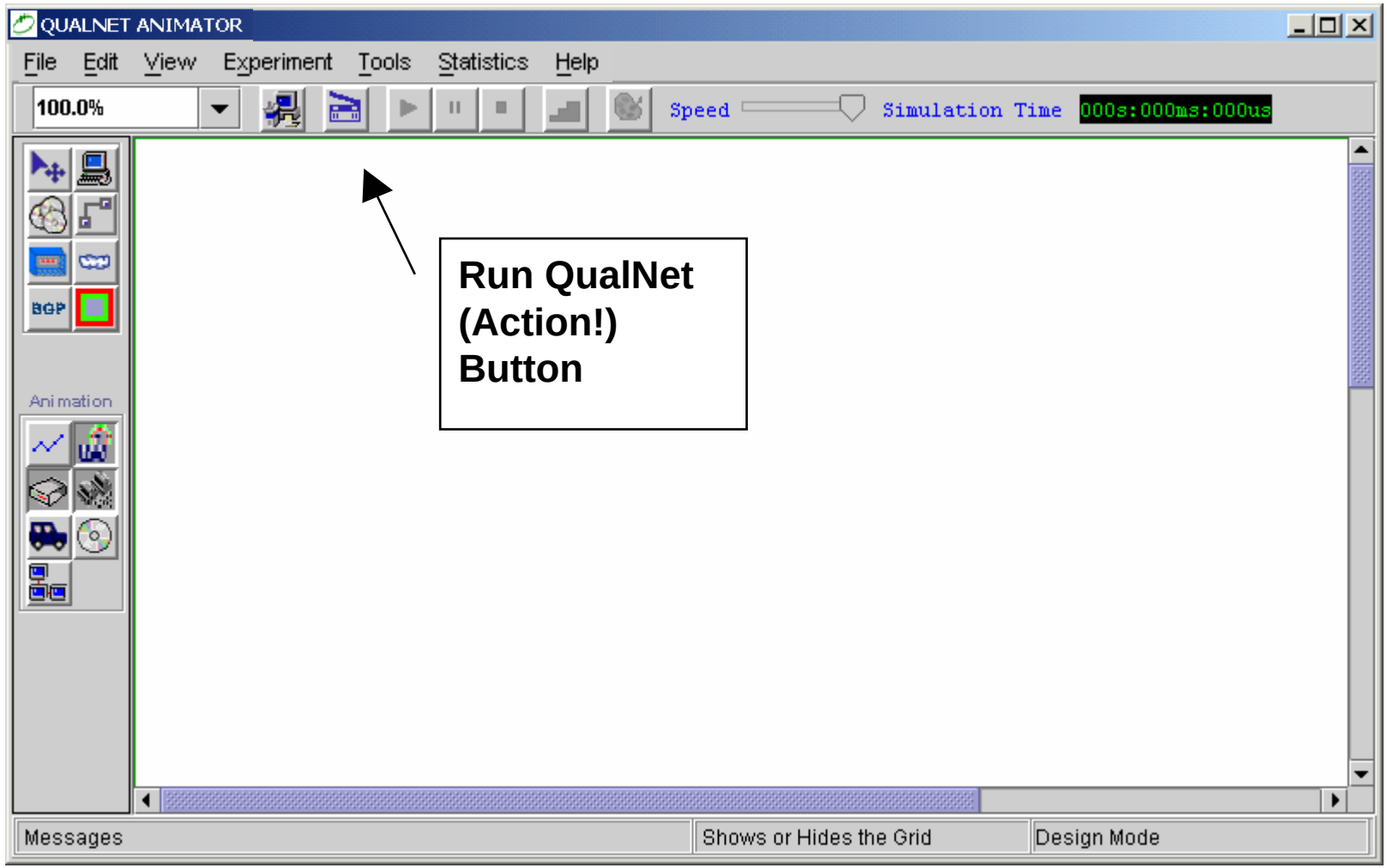
- Click Application button
- Choose Application
- Click source node
- Drag to destination



Statistics

- Some statistics include:
  - APPLICATION-STATISTICS (YES|NO)
  - TCP-STATISTICS (YES|NO)
  - UDP-STATISTICS (YES|NO)
  - ROUTING-STATISTICS (YES|NO)
  - NETWORK-LAYER-STATISTICS (YES|NO)
  - QUEUE-STATISTICS (YES|NO)
  - MAC-LAYER-STATISTICS (YES|NO)
  - PHY-LAYER-STATISTICS (YES|NO)
  - MOBILITY-STATISTICS (YES|NO)
- **Other statistics are protocol specific**
  - BGP-STATISTICS (YES|NO)

Running


QUALNET ANIMATOR
File Edit View Experiment Tools Statistics Help
100.0%
Speed
Simulation Time
000s:000ms:000us
Animation
Run QualNet (Action!) Button
Messages
Shows or Hides the Grid
Design Mode

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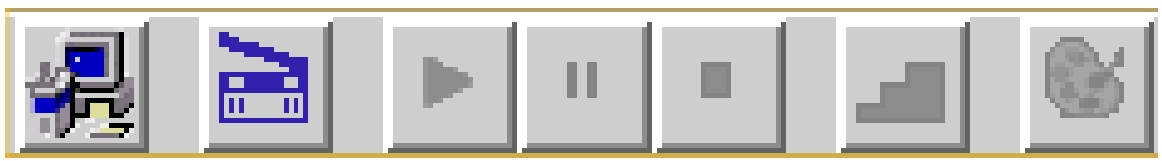
Run Scenario

- Click **Run QualNet (Action!)** button
- From View Menu
  - Select **Animation Filter → By Event → Antenna**
- Press **Play** (watch for a while)
- Press **Pause**, **Step (1S)**
- From Edit menu
  - Select **Set Step Size → By Animation Command to 1**

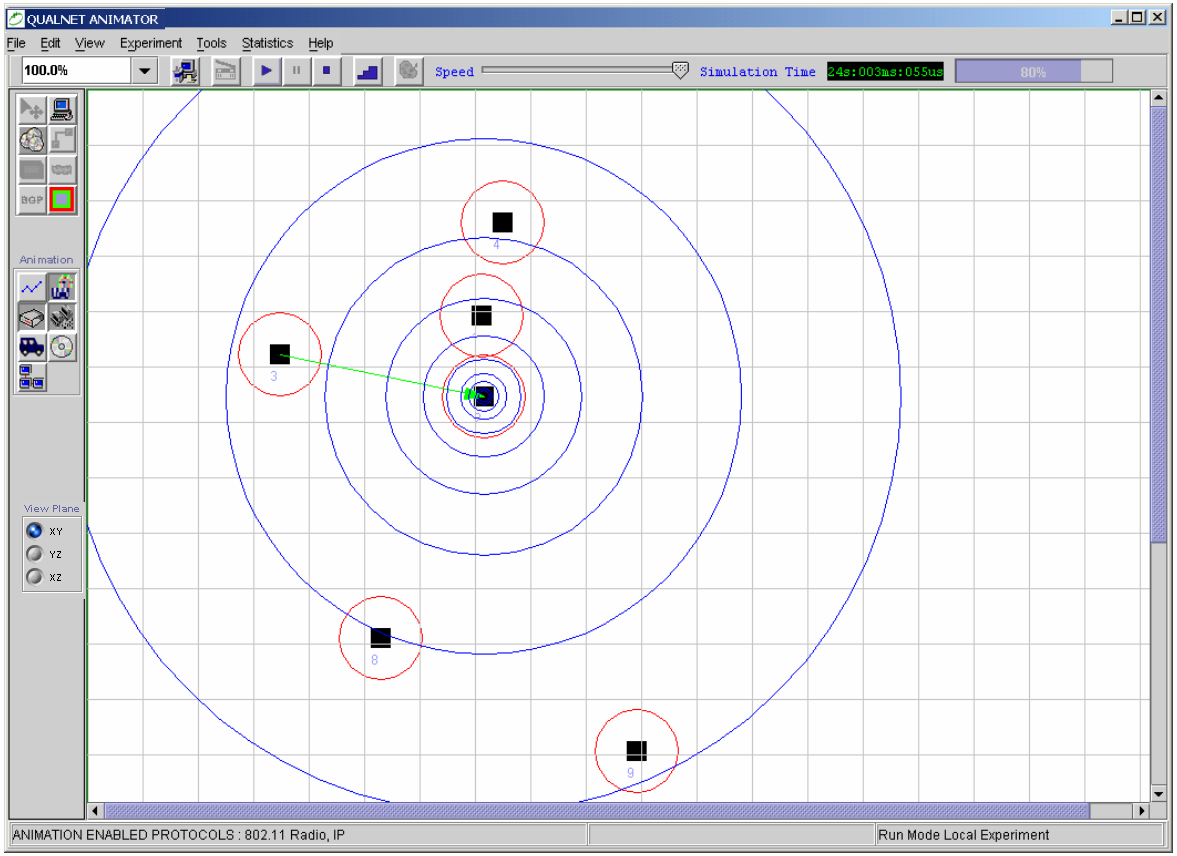
Controlling QualNet Simulator

- **Play**—Plays continuously, resumes from a pause
- **Pause**—Temporarily pauses execution
- **Stop**—Stops QualNet; click **Run QualNet (Action!)** to start over from the beginning
- **Step**—Steps forward in the execution by 1 second



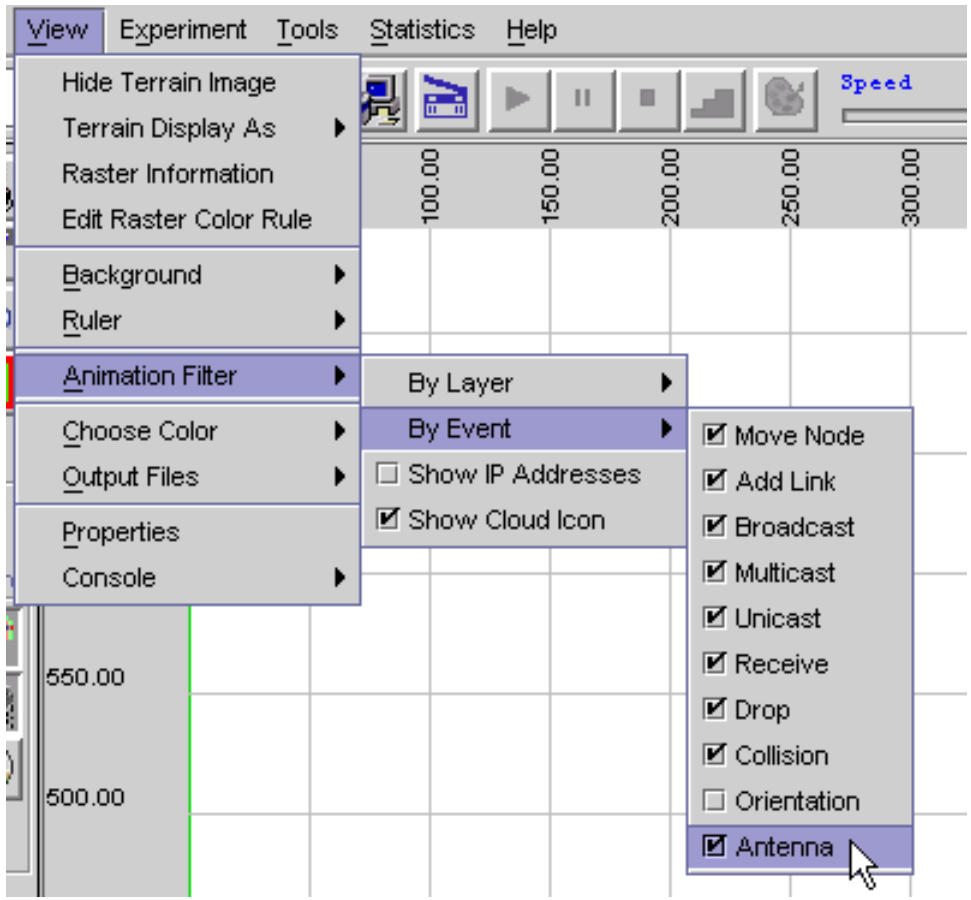
Visualizing the Scenario

- Types of animation
  - Mobility
  - Data transmission
    - send (blue)
    - receive (green)
  - Antenna patterns
  - Orientation
  - Queues



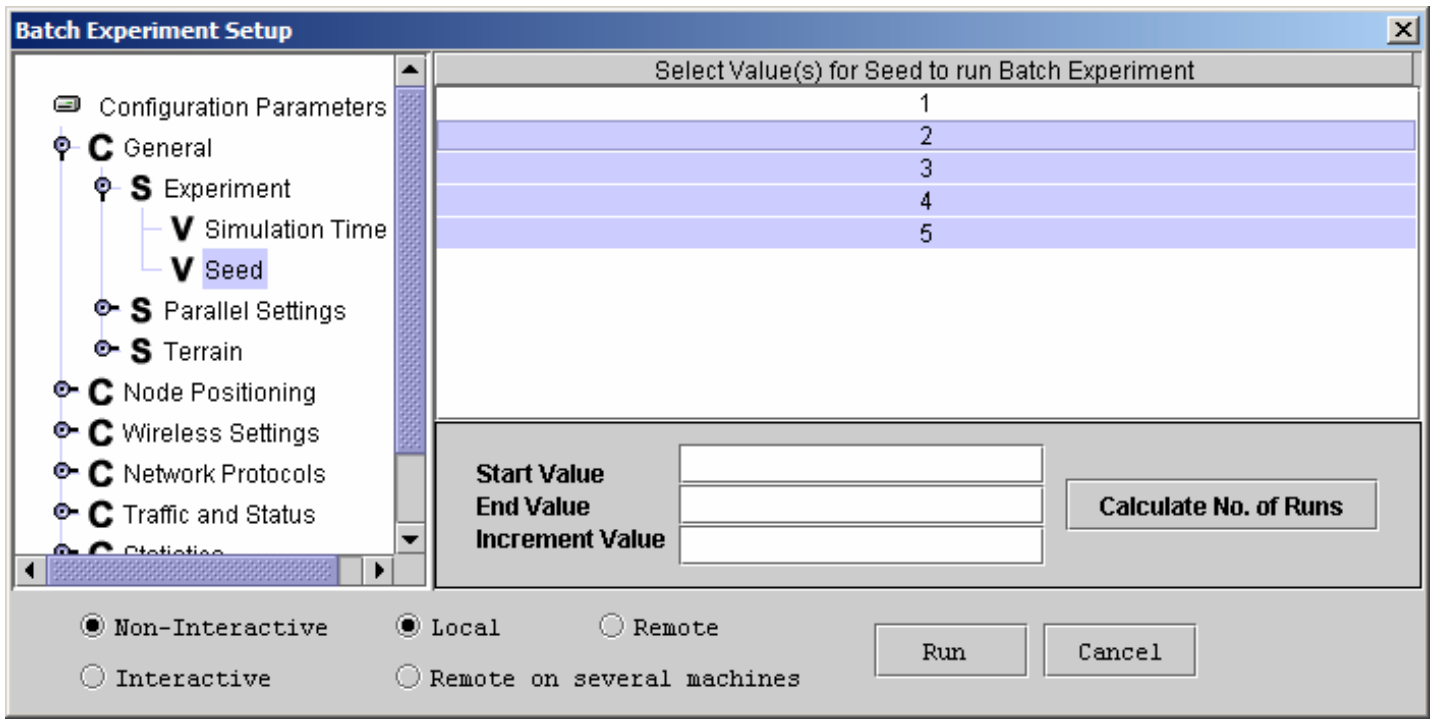
Animation Filtering

- QualNet produces a lot of animation
  - Slowing the GUI and showing more than the user wishes to see.
- Filtering by event
- Filtering by layer



Other Capabilities

- Batch Execution: running several experiments at once.
- Dynamic statistics



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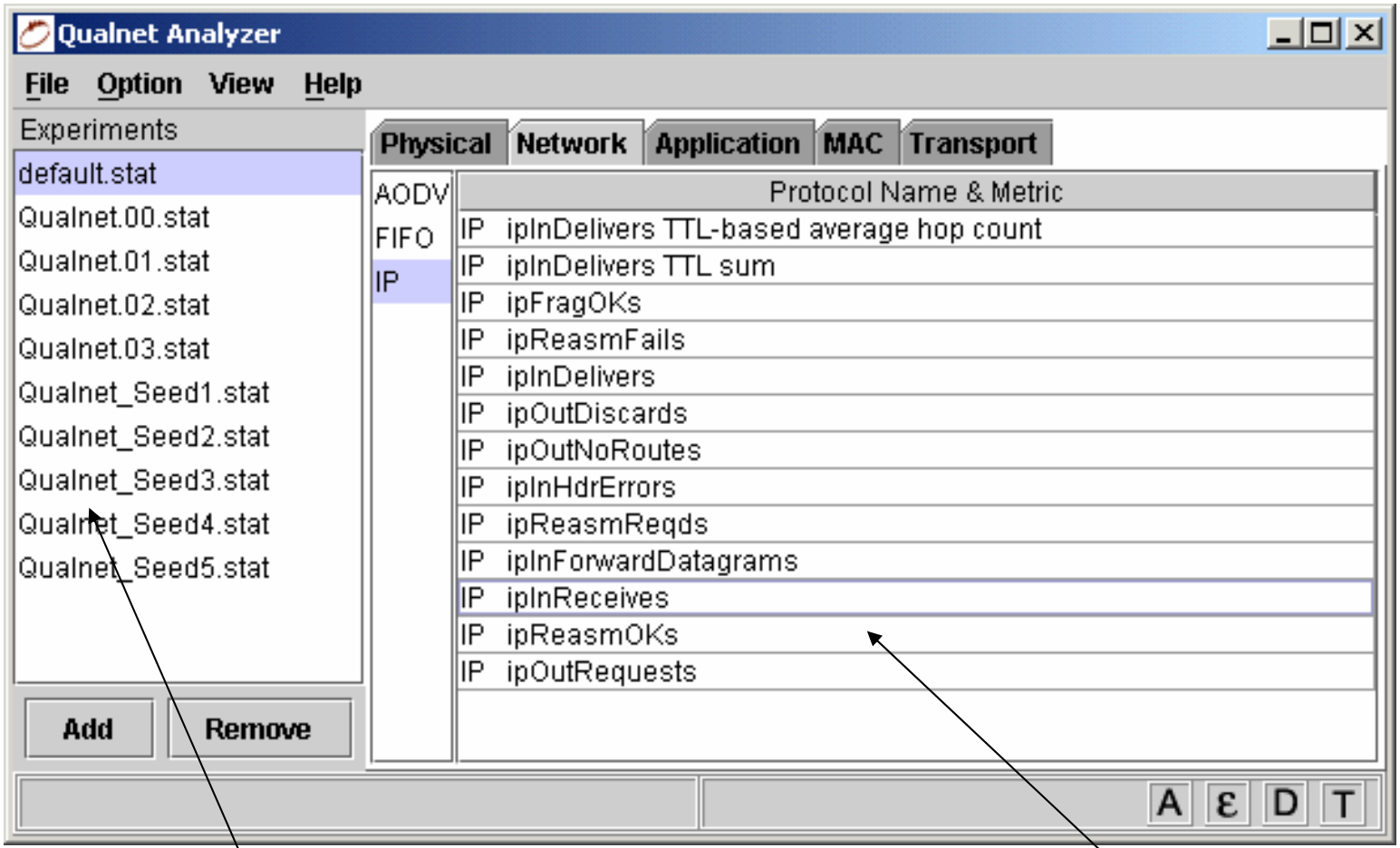
Analyzer Capabilities

- Quickly graphs collected statistics.
- Generates several types of figures for convenient graphical comparison of results
- Generate application-neutral ASCII data files
  - Can be imported into your favorite graphing program (gnuplot, Excel)

Running Analyzer

- After running the batch experiments, start Analyzer
  - Click the Σ symbol in lower-right corner of the GUI, or
  - Run **Analyzer** from Statistics menu
- Note the stats files produced are as follows:
  - Qualnet_Seed1.stat
  - Qualnet_Seed2.stat, etc.

Analyzer Sample Screen



Data Set Window

Metric Window

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Graph Types

- The Analyzer (graphical component) supports the following graph types
  - Single Experiment per-node comparison
    - (Choose one data set, one metric)
  - Multiple Experiment comparison
    - (Choose more than one data set, one metric)
    - Per-node average
    - Experiment-wide sum
  - Histogram

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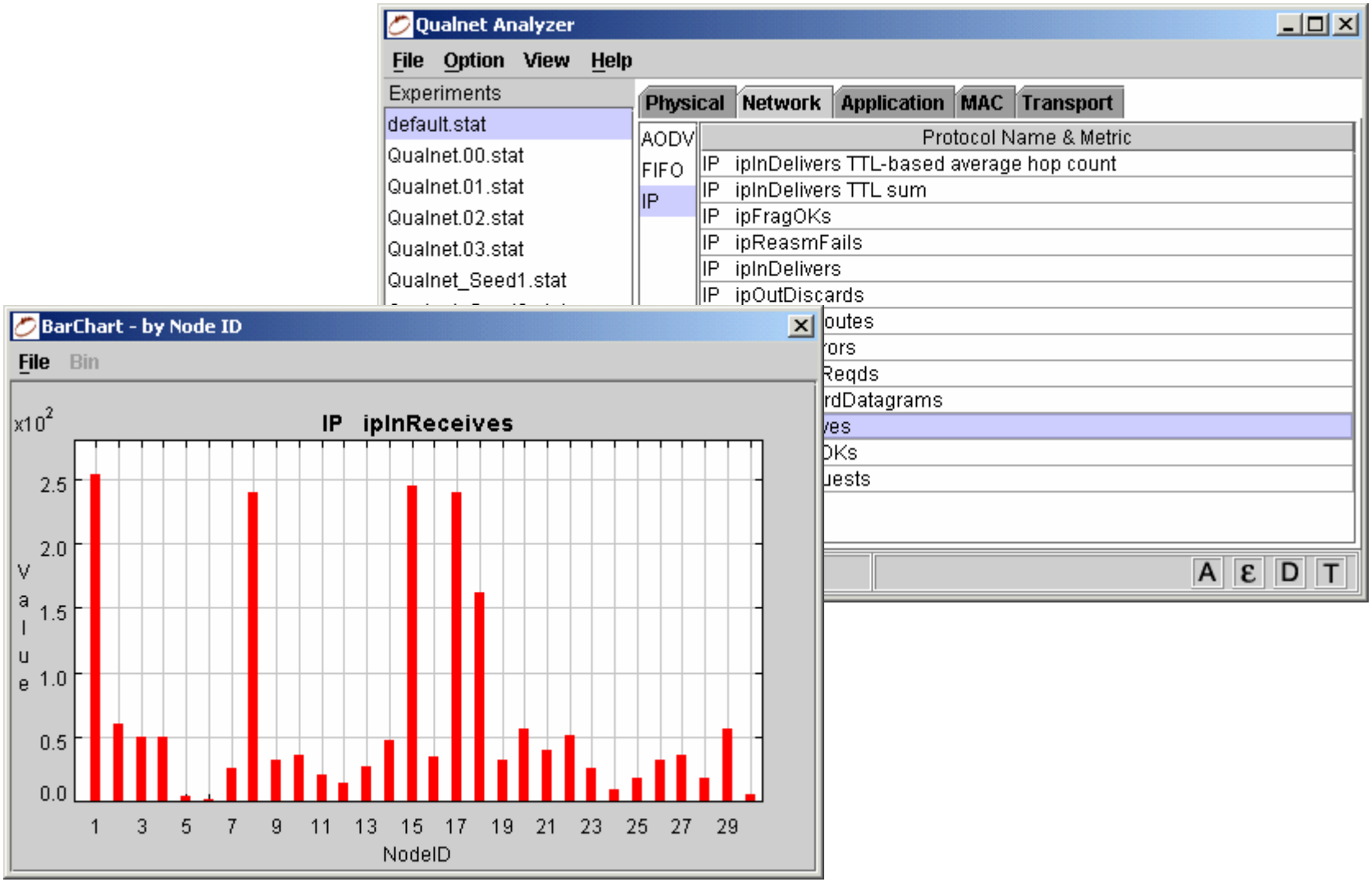
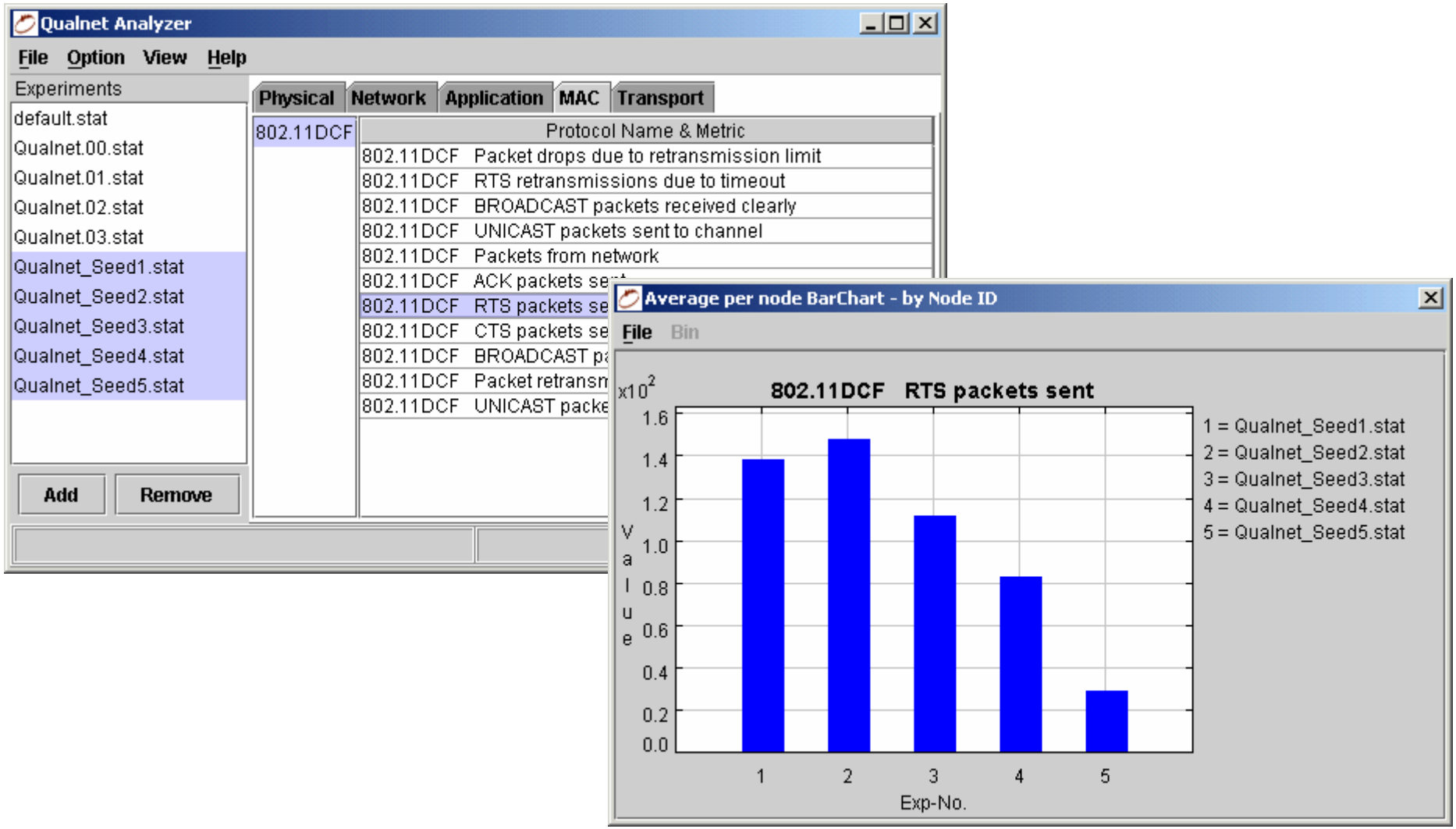
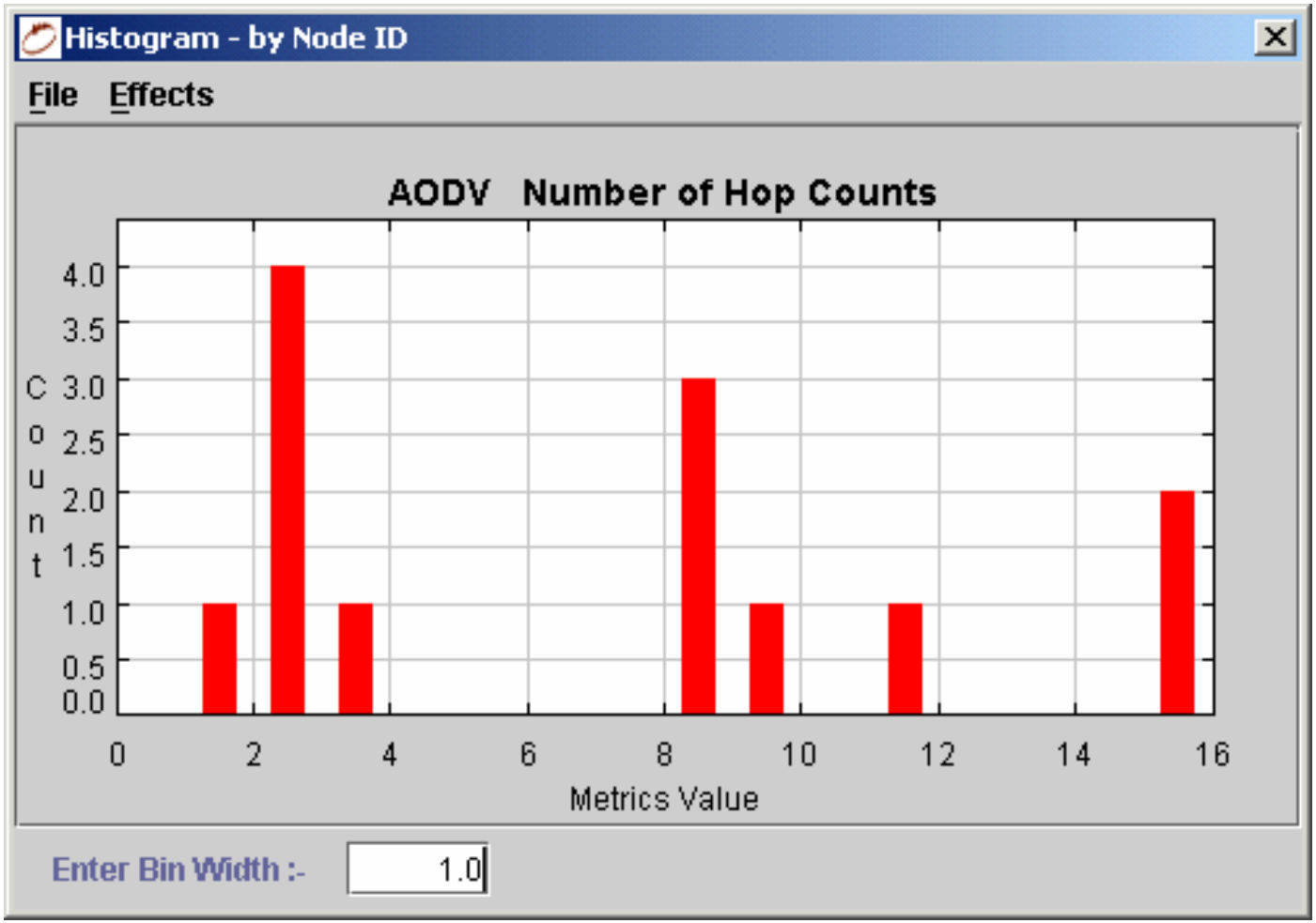
Single Experiment



Multiple Experiment



Histogram


Histogram - by Node ID
File
Effects
AODV Number of Hop Counts
Count
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
10
12
14
16
Metrics Value
Enter Bin Width :-
1.0

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Additional QualNet Resources

- Plain-text explanation for configuration files:
  - **`$QUALNET_HOME/bin/default.*`**
- Qualnet User Manual/Developer's Guide
  - **This is available either in your installation of QualNet or from your QualNet Download Page (emailed to you)**
- QualNet Help Files
  - **http://www.scalable-networks.com/help/index.html**
- Qualnet Community forums
  - http://www.scalable-networks.com/training_and_support/support/forums/index.php