NetSim®

Accelerate Network R & D

Mobile Ad hoc Networks (MANETs)

A Network Simulation & Emulation Software

By

TETCOS LLP

Contact us at

TETCOS LLP

214, 39th A Cross, 7th Main, 5th Block Jayanagar,

Bangalore - 560 041, Karnataka, INDIA.

Phone: +91 80 26630624

E-Mail: sales@tetcos.com

Visit: www.tetcos.com

Contents

1 Introduction

In NetSim's Internetworks library, wireless nodes connect to an Access Point (AP) while in NetSim's LTE and 5G libraries, the mobile nodes (UEs) connect to base stations (eNBs, gNBs). There is no such association between the wireless stations and any fixed infrastructure in MANETs.

A Mobile Ad hoc Network (MANET) is an autonomous system of mobile nodes. In such networks, information transport services are built over a set of arbitrarily located nodes, which are possibly mobile. Every node behaves both like a mobile host and as a wireless router. There are many obvious applications for such networks, including emergency communications, vehicular communications, and military applications.

Such networks have dynamic (sometimes rapidly changing), random, multi-hop topologies that are composed of relatively bandwidth-constrained wireless links. MANETs must therefore support efficient operation in mobile wireless environments by incorporating routing functionality into mobile nodes. Note that such multi-hop networks exploit spatial reuse; transmissions can occur simultaneously on links that are sufficiently separated in space.

In NetSim MANETs, data packets are sent between source-destination pairs by multi-hop relaying. The MANETs in NetSim may operate in isolation or may have bridge nodes to interface with other networks (wired networks or even other MANETs).

NetSim MANET library supports the following protocols.

- Layer 3 Unicast Routing
  - Dynamic Source Routing (DSR)
  - Ad hoc On demand Distance Vector Routing (AODV)
  - Optimized Link state Routing (OLSR)
  - Zone Routing Protocol (ZRP)
- MAC / PHY (interfaced from NetSim Internetworks library)
  - 802.11 a, b, g, n, ac, p, and e

NetSim MANETs component can be interfaced with:

- NetSim Component 6 (IOT) module to run 802.15.4 in MAC/PHY
- NetSim Component 9 (VANETs) module to run IEEE 1609 WAVE in MAC/PHY
- NetSim TDMA Radio Networks (Add on) to run TDMA/DTDMA in MAC/PHY

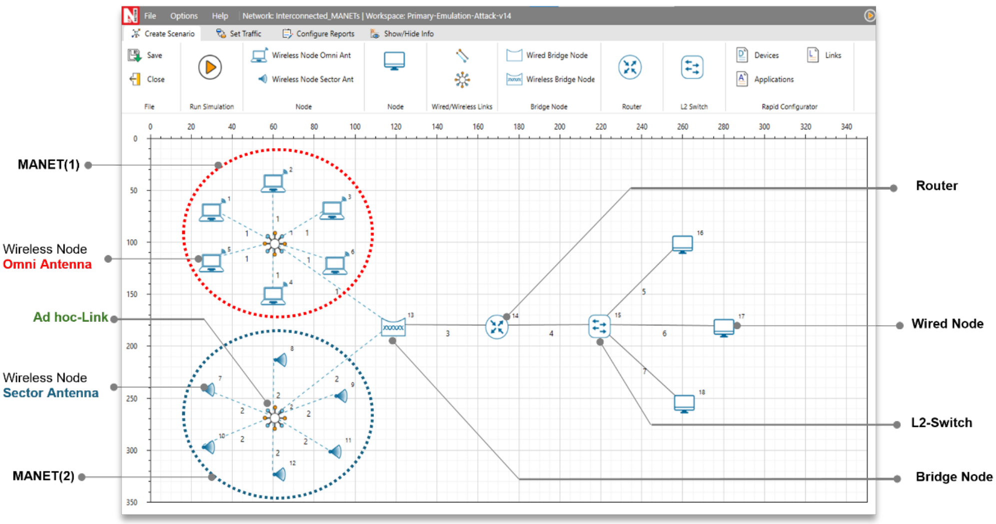

Figure 1-1: *A typical MANET Network scenario in NetSim. The topology shows multiple MANETs connected via a bridge node, and connected to an external network through a router*

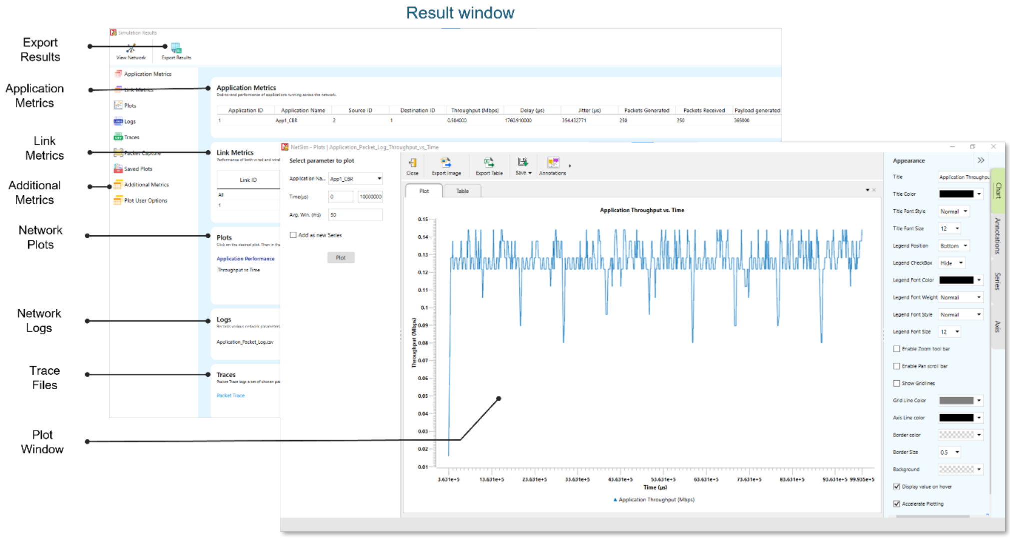

Figure 1-2: *The Result dashboard and Plot window shown in NetSim after completion of simulation*

The digital communication system employed, the transmit power used, and the radio propagation characteristics of the environment determine the "links" in the network.

Performance analysis of wireless ad hoc networks is a challenging task because such analysis must consider the interactions between the wireless physical layer, radio propagation, multiple access, random topology, routing, and the characteristics of the application that generates the traffic carried by the network. Therefore, unlike wired and fixed-topology networks, understanding and optimizing the performance of MANETs is a difficult undertaking owing to the complex interaction between the various "layers" of the network.

2 Simulation GUI

In the Main menu select New Simulation → Mobile Ad hoc networks as shown in Figure 2-1.

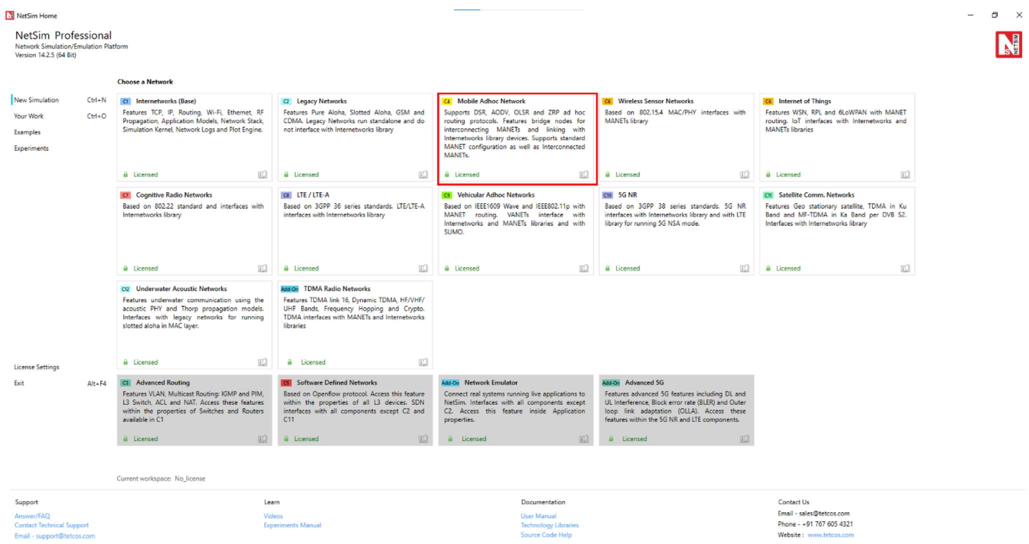

Figure 2-1: *NetSim Home Screen*

2.1 NetSim MANET Network Setup

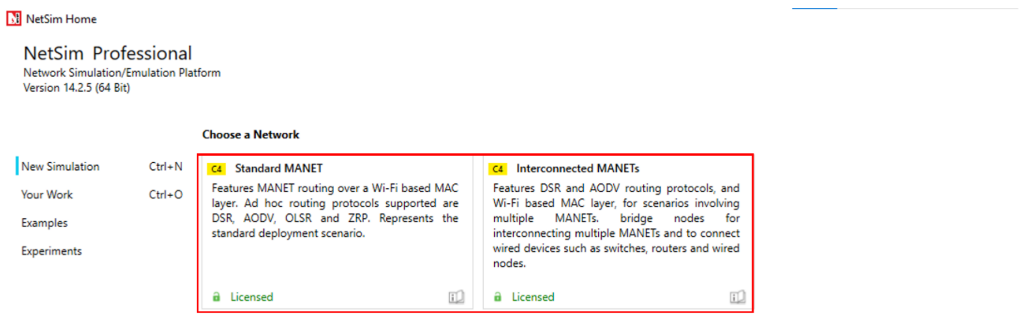

Figure 2-2: *MANET Network Setup window.*

2.1.1 Deployment Architecture

The deployment options have been grouped into 2 categories. Standard MANET option where the scenario comprises only wireless nodes without any bridge node. Interconnected MANETs option allows users to connect two or more MANETs using a bridge node.

Standard MANET: In Standard MANET, a network scenario can be created using ad-hoc links and wireless nodes. Standard MANET supports DSR, AODV, OLSR and ZRP Routing protocols.

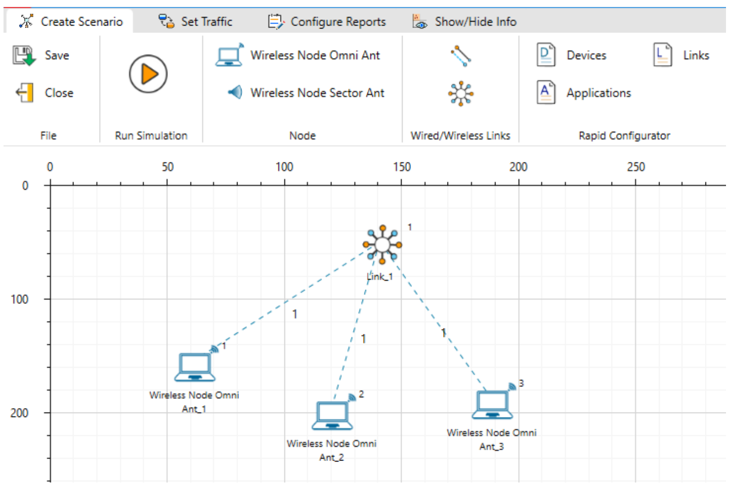

Figure 2-3: *A Single MANET scenario.*

Interconnected MANETs: In Interconnected MANETs, a network scenario can be created using multiple MANETs, bridge nodes for interconnecting multiple MANETs, and wired devices like switches, routers, and nodes. Interconnected MANETs support only DSR and AODV routing protocols.

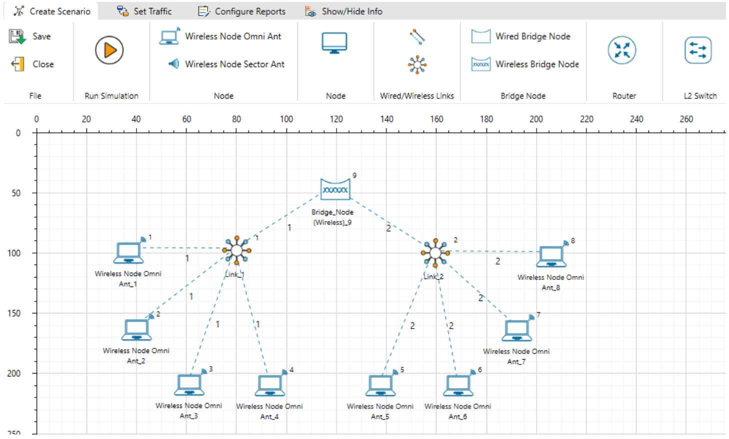

Figure 2-4: *Interconnected (Multiple) MANET Scenario*

2.2 Fast Configuration

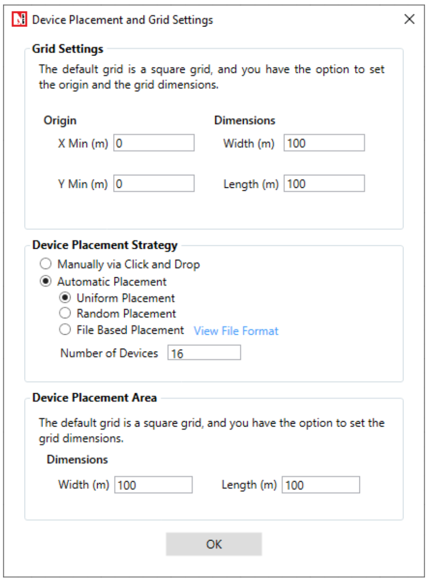

Figure 2-5: *Fast Configuration window*

The Fast Config window allows users to define device placement strategies and conveniently model large network scenarios especially in networks such as MANET, TDMA Radio Networks, WSN, UWAN and IoT. The parameters associated with the Fast Config Window are explained below:

(i) Grid Origin: The ‘Grid Origin’ refers to the intersection point of the system’s axes. NetSim supports any (X, Y) setting for the origin and not just (0, 0).

(ii) Grid Dimension: The width parameter represents the maximum extent along X from the origin and the height parameter represents the maximum extent along Y from the origin.

(iii) Device placement area: The “Device Placement Area” allows users to specify the width and length of the area where devices are used when using the auto placement utility. This area must be less than or equal to the “Grid Area”.

2.2.1 Device Placement

Automatic Placement

- Uniform Placement: Devices are placed uniformly with equal gap between the devices in area based on the side length. This requires users to specify the number of devices as square numbers, such as 1, 4, 9, 16, etc.
- Random Placement: Devices are placed randomly in the grid environment within the area based on side length.
- File Based Placement: In order to place devices in user defined locations file-based placement options can be used. The file has the following general format:
- `<DEVICE NAME>,<DEVICE TYPE>,<X COORDINATE>,<Y COORDINATE>`

Where,

DEVICE NAME – The name assigned to the device.

DEVICE TYPE – The unique device identifier specific to each type of device in NetSim.

The following table provides the DEVICE TYPEs of all possible devices for networks with support for Device Fast Configuration:

Table 2-1: *Fast Configuration window supports different networks.*

NETWORK	DEVICE_TYPE
MANET	Wireless Node Omni Antenna | Wireless Node Sector Antenna | Wired Bridge Node | Wireless Bridge Node | Wired Node | Router | L2_Switch
WSN	Sensors | Sink node
IOT	IoT Sensors | Gateway | Wired Node | IoT Router | Access Point | L2 Switch

X COORDINATE – The X-coordinate value of the device.

Y COORDINATE – The Y-coordinate value of the device.

Eg: MANET File-Based Placement.txt

```
Wireless Node Omni Antenna, WirelessNode,100,150
Wireless Node Omni Antenna, WirelessNode,150,100
Wireless Node Omni Antenna, WirelessNode,100,100
Wireless Node Omni Antenna, WirelessNode,50,50
```

Open NetSim, and in the Main menu, select New Simulation ▷ Mobile Ad Hoc Networks. Select File Based Placement option under Automatic Placement and give the path of the text file as shown in Figure 2-6 below.

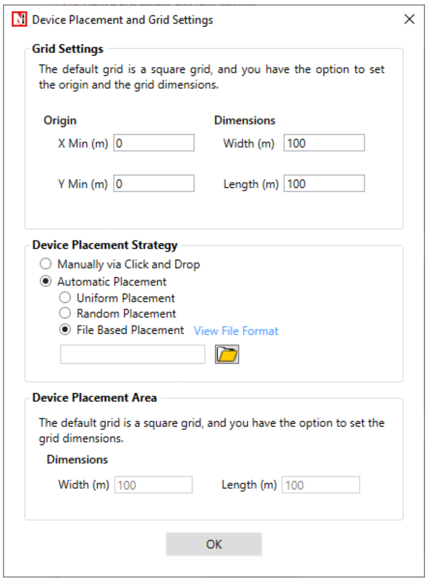

Figure 2-6: *Device placement strategy to File based placement*

After providing the path, clicking on OK will display the MANET network shown below, where all devices are placed as per the positions given in the text file as shown in Figure 2-7.

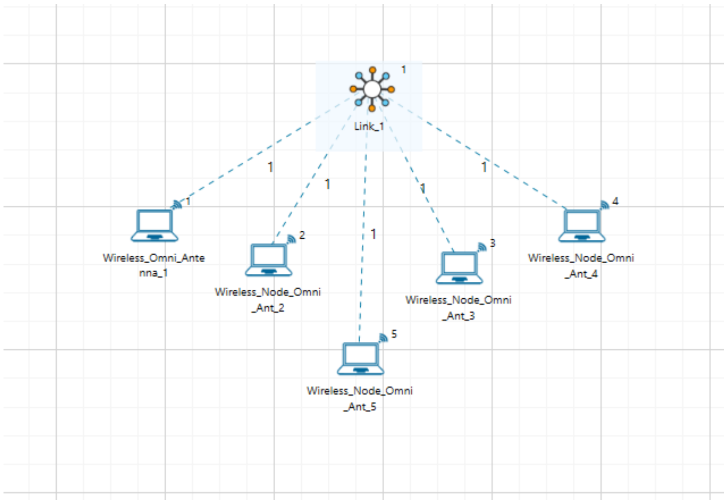

Figure 2-7: *Network Topology*

Number of Devices: It is the total number of devices that are to be placed in the grid environment. It should be a square number in case of uniform placement.

Manually Via Click and Drop

Selecting this option will load a link in the grid environment, where users can add devices by clicking and dropping them as required.

2.3 Create Scenario

2.3.1 Wireless Node

A MANET consists of mobile platforms – simply referred to as "wireless nodes" in NetSim – which are free to move about arbitrarily. They are IP addressable devices. Wireless Nodes in NetSim MANETs library act as both end-nodes and routers. These nodes make routing decisions using the IP fabric.

In NetSim MANETs, each node can have only one wireless interface.

2.3.2 Bridge Node

Bridge Node acts as a bridge/interface/gateway between multiple MANETs. Packets from one MANET can be routed to another MANET via a Bridge Node as shown in Figure 2-8.

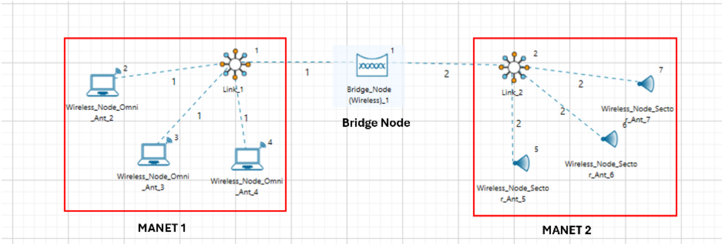

Figure 2-8: *Multiple MANETs connected via a Bridge node*

Each Bridge Node has 24 interfaces. When connecting bridge nodes to one another or to routers, care should be taken to ensure that the static routes are set.

NetSim supports Wired and Wireless Bridge Nodes as shown in Figure 2-9/Figure 2-10.

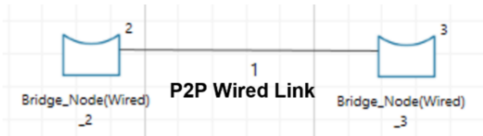

Figure 2-9: *Two wired bridge nodes can be connected to each other using P2P wired links*

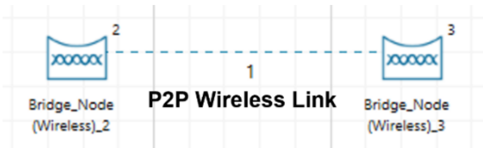

Figure 2-10: *Two wireless bridge nodes can be connected to each other using P2P wireless links*

A wired bridge node cannot be connected to a wireless bridge node and vice versa.

2.3.3 Link

At a given point in time, depending on the nodes' positions and their transmitter and receiver coverage patterns, transmission power levels and interference levels, wireless connectivity in the form of a random multi-hop graph or "ad hoc" network exists between the nodes. This ad hoc topology may change with time as the nodes move or adjust their transmission and reception parameters. Ad hoc links are used in NetSim to visually represent this connection of devices on an ad hoc basis as shown in Figure 2-11.

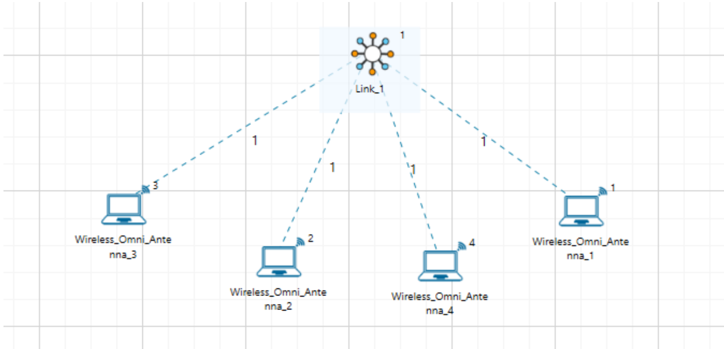

Figure 2-11: *Mobile Ad hoc Network*

Wireless links generally have significantly lower capacity than their hardwired counterparts. In addition, the realized throughput of wireless communications after accounting for the effects of multiple access, fading, noise, and interference conditions, etc. is often much less than a radio's maximum transmission rate.

Connecting ad hoc links is a one step process, by default one ad hoc link will be present in the grid. Users need to drop wireless nodes from the create scenario tab which gets automatically connected to ad hoc link.

An ad hoc link is a multipoint-to-multipoint link. When connected to a device its interface is set to 0 in NetSim.

2.4 Set Node, Link and Application Properties

Click on the appropriate node or link to open a right-side property panel. Then modify the parameters according to the requirements.

- Global Properties: Certain properties are global in nature, i.e., changing properties in one node will automatically reflect in the others in that network.
- In case of MANETs, in Wireless Nodes, Routing Protocol in Network Layer is global and all user editable properties in Datalink Layer, Physical Layer and Power are Local.
- The following are the main properties of wireless node omni ant in Datalink and Physical layers as shown in Figure 2-12/Figure 2-13.

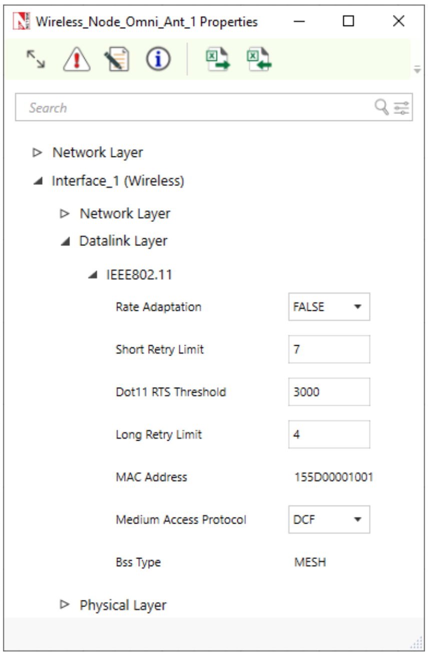

Figure 2-12: *Datalink layer properties window for wireless node omni ant*

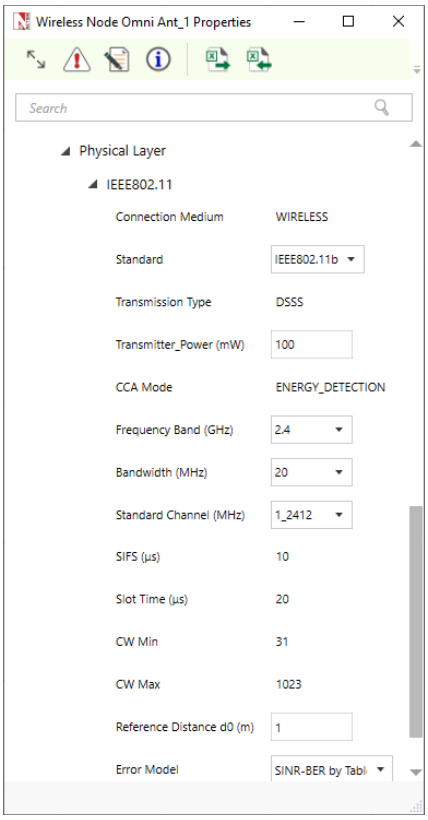

Figure 2-13: *Physical layer properties window for wireless node omni ant.*

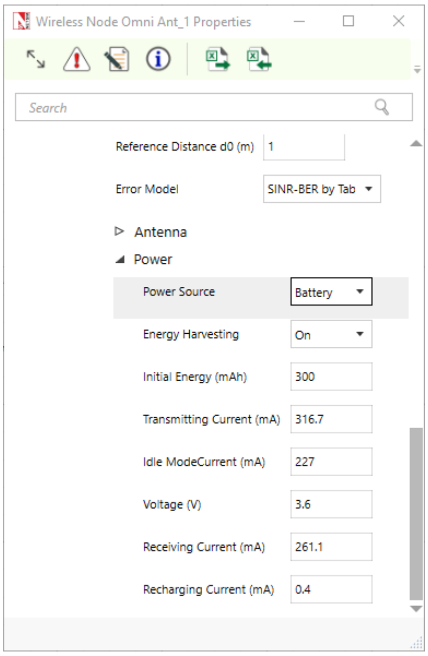

Figure 2-14: *Battery Model for Wireless node omni ant.*

Configure an application between any two nodes by selecting any application from the Set Traffic tab. Clicking on the application will open a right-side property panel where you can set the properties according to the requirement.

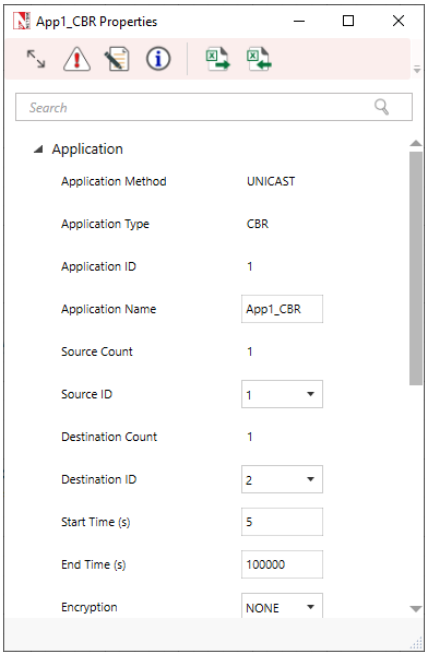

Figure 2-15: *Application icon and Configuration Window*

NOTE: For MANET networks the application start time should be a minimum of 5s, since this amount of time is required for convergence of OLSR/ZRP.

2.5 Enable Packet Trace, Event Trace (Optional)

To enable packet trace and event trace click on the configure reports tab in the ribbon on the top as shown below. For detailed help about the packet and event trace, please refer to sections 8.4 and 8.5 in the User Manual.

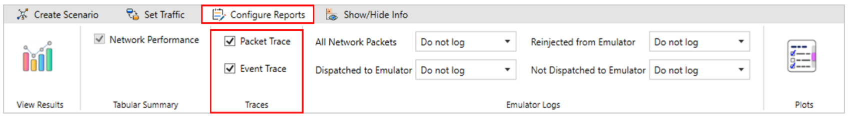

Figure 2-16: *Enable Packet Trace, Event Trace & Plots options on top ribbon.*

2.6 Enable protocol specific logs and plots

NetSim provides protocol-specific logs for MANET libraries, which users can enable before running a simulation. These can be enabled by clicking on configure reports in top ribbon ▷ clicking on plots ▷ choosing as desired, and running the simulation.

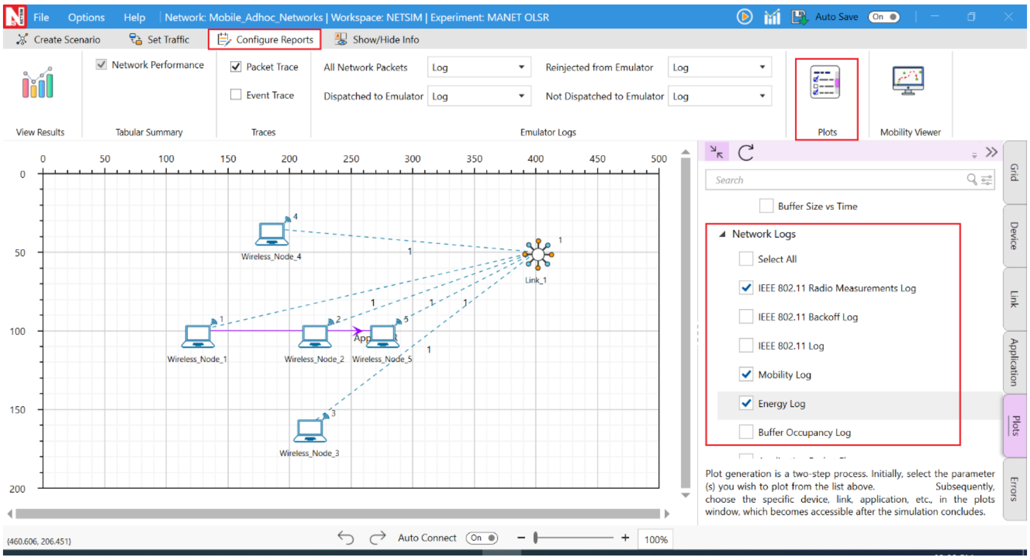

Figure 2-17: *Enabling the Network logs in MANET*

Similarly, users can enable the plots for Wi-Fi radio measurements and energy.

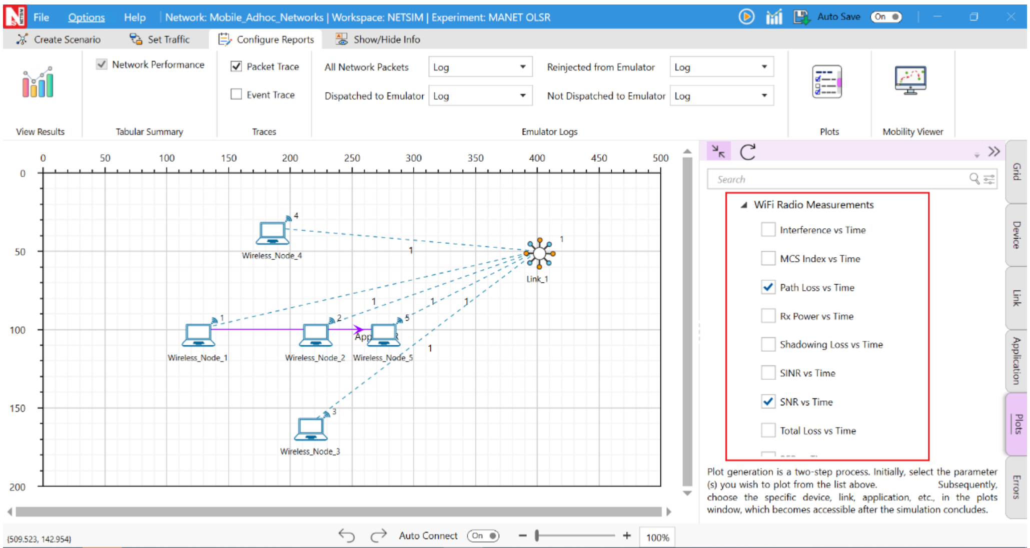

Figure 2-18: *Enabling the Plots in MANET*

2.7 GUI Configuration Parameters

Table 2-2: *Datalink layer, Network layer and Physical layer properties for Wireless Node Omni and Sector Ants.*

Parameter	Scope	Range	Description
Interface(Wireless) – Datalink Layer			
Rate Adaptation	Global (Standard MANETs) / Per MANET (Interconnected MANETs)	False	The algorithm is similar to Receiver based Auto Rate (RBAR) algorithm. In this, the PHY rate gets set based on the target PEP (packet error probability) for a given packet size. The adaptation is termed as “False” since the rate is pre-determined as per standard and there is no subsequent adaptation.
		Minstrel	Rate adaptation algorithm implemented in Linux.
		Generic	The algorithm is similar to the Auto Rate Fallback (ARF) algorithm. In this algorithm (i) rate goes up one step for 20 consecutive packet successes, and (ii) rate goes down one step after 3 consecutive packet failures.
Short Retry Limit	Local	1 to 255	Determines the maximum number of transmission attempts of a frame. The length of MPDU is less than/equal to Dot11 RTS Threshold value, made before a failure condition is indicated.
Long Retry Limit	Local	1 to 255	Determines the maximum number of transmission attempts of a frame. The length of MPDU is greater than Dot11 RTS Threshold value, made before a failure condition is indicated.
Dot11 RTS Threshold	Local	0 to 4692480	The size of packets (or A-MPDU if applicable) above which RTS/CTS (Request to Send / Clear to Send) mechanism gets triggered.

Continued on next page

Table 2-2: *(continued)*

Parameter	Scope	Range	Description
MAC Address	Fixed	Auto Generated	The MAC address is a unique value associated with a network adapter. This is also known as hardware address or physical address. This is a 12-digit hexadecimal number (48 bits in length).
Physical Type	Global	DSSS	Direct Sequence Spread Spectrum. The physical type of parameter is set to DSSS if the standard selected is IEEE802.11b.
		OFDM	Orthogonal Frequency Division Multiplexing is utilized as a digital multi-carrier modulation method. The physical type of parameter is set to OFDM if the standard selected is IEEE802.11a, g and p.
		HT	Operates in frequency bands 2.4GHz or 5GHz band. The physical type parameter is set to HT if the standard selected is IEEE802.11n.
		VHT	The physical type parameter is set to VHT if the standard selected is IEEE802.11ac.
Medium Access Protocol	Local	DCF	DCF is the process by which CSMA/CA is applied to Wi-Fi networks. DCF defines four components to ensure devices share the medium equally: Physical Carrier Sense, Virtual Carrier Sense, Random Back-off timers, and Interframe Spaces (IFS). DCF is used in non-QoS WLANs.

Continued on next page

Table 2-2: *(continued)*

Parameter	Scope	Range	Description
Medium Access Protocol	Local	EDCAF	QoS was introduced in 802.11e and is achieved using enhanced distributed channel access functions (EDCAFs). EDCA provides differentiated priorities to transmitted traffic, using four different access categories (ACs). With EDCA, high-priority traffic has a higher chance of being sent than low-priority traffic: a station with high priority traffic waits a little less before it sends its packet, on average, than a station with low priority traffic. **Access Categories under EDCAF:** AC_BK, AC_BE, AC_VI and AC_VO. **CWmin (Slots):** This attribute specifies the value of the minimum size of the window that is used by an AP for a particular AC for generating a random number for the backoff. The value of this attribute is such that dot11EDCATableCWmin could always be expressed in the form of $2^X - 1$, where X is an integer. The default value for this attribute is CWmin. Range is 0 to 255. **CWmax (Slots):** This attribute specifies the value of the maximum size of the window that is used by an AP for a particular AC for generating a random number for the backoff. The value of dot11EDCATableCWmax is such that it could always be expressed in the form of $2^X - 1$, where X is an integer. The default value for this attribute is CWmax. Range is 0 to 65535. **AIFSN (Slot):** This attribute specifies the number of slots, after a SIFS duration, that the STA for a particular AC senses the medium is idle before transmitting or executing a backoff. The default value for this attribute is 7. Range is 2 to 15. **MAX TXOP:** This attribute specifies the maximum number of microseconds of an EDCA TXOP for a given AC. The default value for this attribute is 0 for all PHYs. Range is 0 to 65535, with reference to the 802.11 standard. **MSDU Lifetime:** This attribute specifies, in TU, the maximum duration an MSDU for a given AC would be retained by the MAC before it is discarded. Range is 0 to 4294967295 TU.

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Table 2-2: *(continued)*

Parameter	Scope	Range	Description
OCBA Activated	Local	True or False	This parameter determines the type of standard to be chosen for the OFDM physical type. The standard is set to IEEE802.11p if OCBA is True. The standard is set to IEEE802.11a and g if OCBA is False.
BSS Type	Fixed	Auto Generated	The BSS type is fixed to Infrastructure mode. The wireless device can communicate with each other or with a wired network.
Interface(Wireless) – Physical Layer			
Protocol	Fixed	IEEE 802.11	Defines the MAC and PHY specifications like IEEE802.11a/b/g/n/ac/p for wireless connectivity for fixed, portable and moving stations within a local area.
Connection Medium	Fixed	Auto Generated	Defines how the devices are connected or linked to each other.
Standard	Global (Standard MANETs) / Per MANET (Interconnected MANETs)	IEEE 802.11 a/b/g/n/ac/p	Refers to a family of specifications developed by IEEE for WLAN technology. The IEEE standards supported in NetSim are IEEE 802.11 a, b, g, n, ac and p. 802.11a provides up to 54 Mbps in the 5GHz band. 802.11b provides 11 Mbps in the 2.4GHz bands. 802.11g provides 54 Mbps transmission over short distances in the 2.4 GHz band. 802.11n adds up MIMO. 802.11ac provides support for wider channels and beamforming capabilities. 802.11p provides support to Intelligent Transportation Systems.
Transmission Type	Fixed	DSSS	Direct Sequence Spread Spectrum (DSSS), a radio transmission technique that spreads a narrowband signal across a wider carrier frequency band. Each transmission is assigned a 10-bit pseudorandom binary code sequence, which comprises a series of ones and zeros in a seemingly random pattern known to both the transmitter and receiver.
		OFDM	Orthogonal Frequency Division Multiplexing (OFDM), a frequency-division multiplexing (FDM) scheme utilized as a digital multi-carrier modulation method. A large number of closely-spaced orthogonal sub-carriers are used to carry data. The data is divided into several parallel data streams or channels, one for each sub-carrier. Each sub-carrier is modulated with a conventional modulation scheme such as Quadrature Amplitude Modulation or Phase Shift Keying at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth.

Continued on next page

Table 2-2: *(continued)*

Parameter	Scope	Range	Description
		HT	High Throughput (HT). HT stands for High Throughput. The IEEE 802.11 HT STA operates in frequency bands 2.4 GHz / 5 GHz band.
		VHT	Very High Throughput (VHT). VHT stands for Very High Throughput. The IEEE 802.11 VHT STA operates in frequency bands below 6 GHz excluding the 2.4 GHz band. Most VHT features, among other benefits, increase the maximum throughput achievable between two VHT STAs over that achievable using HT (High Throughput) features alone.
Transmit Power	Local	0 to 1000	Transmitted signal power. Note that the transmit power is not split among the antennas. This value is applied to each antenna in a multi-antenna transmitter. Unit is mW.
CCA Mode	Fixed	Auto generated	A mechanism to determine whether a medium is idle or not. Includes Carrier sensing and energy detection.
Frequency Band	Local	2.4, 5, 5.9 (Depends on the standard chosen)	The centre frequency of the band at which the device is operating. Unit is GHz.
Bandwidth	Local	5,10, 20, 40, 60, 80, 160 (Depends on the standard chosen)	Bandwidth is a range of frequencies occupied by radio communication signal to carry most of its energy. Unit is MHz.
Standard Channel	Local	Depends on the standard chosen	The channel options defined in the standards. The options would also depend on the frequency band if the standard supports multiple bands.
SIFS	Fixed	Auto Generated	The time interval required by a wireless device in between receiving a frame and responding to the frame. Unit is microseconds.
Slot Time	Fixed	Auto Generated	Time is quantized as slots in Wi-Fi. Unit is microseconds.
Guard Interval	Local	400 and 800	Guard Interval is intended to avoid signal loss from multipath effect. Unit is nanoseconds.
MCS Selection	Local	Auto Rate Fallback, Fixed	MCS selection in Wi-Fi impacts data rates and efficiency. Auto Rate Fallback adapts the MCS based on signal quality. Fixed MCS locks the MCS. Default Value: Auto Rate.
Data MCS	Local	802.11b: 0–3, 802.11a/g/p: 0–7, 802.11n: 0–7, 802.11ac: 0–9 (MCS 9 not available for 20MHz in VHT)	Allows selection of the MCS value for different Wi-Fi standards. Determines the modulation and coding scheme. Default Value: 0.
Data PHY Rate (Mbps)	Local	Determined by selected Data MCS and Wi-Fi standard	Shows the physical layer data rate based on the chosen modulation and coding scheme.

Continued on next page

Table 2-2: *(continued)*

Parameter	Scope	Range	Description
CW Min	Fixed	Auto generated	The minimum size of the Contention Window in units of slot time. The CW min is used by the MAC to calculate the back off time for channel access during a carrier sense.
CW Max	Fixed	Auto generated	The maximum size of the Contention Window in units of slot time. The CW is doubled progressively when collisions occur.
Error Model	Local	SINR-BER-By-Table, SINR-BER-By-Formula	Specifies how the Bit Error Rate (BER) is calculated: BER is determined based on predefined tables mapping SINR to BER. BER is calculated using mathematical formulas that account for the modulation and coding schemes used, based on the SINR value.
Antenna Height	Local	0 to 100m	It is used in the pathloss calculation in the following models: Cost231 Hata Urban, Cost231 Hata SubUrban, Hata Urban, Hata SubUrban and Two Ray. This parameter has no effect when using any of the other pathloss models. Default:0.0 m.
Antenna Gain	Local	0 to 1000 dB	A relative measure of an antenna's ability to direct or concentrate radio frequency energy in a particular direction or pattern. The measurement is typically measured in dBi (Decibels relative to an isotropic radiator).
Antenna Type	Fixed	Omnidirectional or Sector antenna	NetSim supports two types of Antenna, Omnidirectional and Sector Antennas.
Wireless Node Sector Ant			
Antenna Model	Fixed	–	Currently NetSim only supports 2D passive antenna per 3GPP TR 37.840.
Orientation Angle	Local	0°–360°	NetSim implements a 2D parabolic sector antenna as per 3GPP TR 37.840. The boresight angle denotes the direction of maximum gain, or the highest radiated power. The angle is defined to start at 0 from the positive X-axis. If positive Y points downward, the angle increases on clockwise rotation from the positive X-axis. If positive Y points upward, the angle increases in an anti-clockwise direction from the positive X-axis. The units for the boresight angle are in degrees.
Element Gain (dB)	Local	−50 to +50	This is the maximum directional gain of the radiation element (in dB). The default value is 8 dBi.
Front to Back Ratio (dB)	Local	10–40	The ratio of power gain between the front and rear of a directional antenna.
Beam Width	Local	0–90	The 3 dB, or half power, beamwidth of the antenna is defined as the angular width of the radiation pattern, between points 3 dB down from maximum beam level (beam peak).
Power Model			

Continued on next page

Table 2-2: *(continued)*

Parameter	Scope	Range	Description
Power Source	Local	Main Line or Battery	MANETs communicate with each other using battery power. By default, the power model is set to Main Line, which represents a general-purpose alternating current (AC) electric power supply. The power model is user-configurable, with adjustable properties.
Energy Harvesting	Local	On or Off	Energy harvesting is the process of deriving energy from external sources (e.g., solar power, thermal energy, wind energy, and kinetic energy), capturing it, and storing it for use in small, wireless autonomous devices, such as those in wearable electronics and wireless sensor networks. NetSim supports an abstract energy harvesting model in which a specified amount of energy (calculated from the recharging current and specified voltage) is periodically added to the remaining energy of the node to replenish the battery. This feature can be turned on or off.
Initial Energy	Local	0.001–1000 mAh	A node has an initial value which is the level of energy the node has at the beginning of the simulation.
Transmitting Current	Local	0–5000 mA	In the Transmitting mode (Tx mode), the node consumes energy to transfer packets or data. The amount of energy consumed in this mode depends on the number of packets sent by the node; the greater the number of packets, the more energy is consumed.
Idle Mode Current	Local	0–500 mA	In idle mode, a node doesn't transmit or receive data but still listens to the wireless medium for potential packets and new nodes. This consumes less energy than sending or receiving, as no active communication occurs.
Voltage	Local	0–10 V	Voltage is a measure of the energy carried by the charge.
Receiving Current	Local	0–1000 mA	In the Receiving mode (Rx mode), the nodes are actively listening to the incoming data, it consumes the energy as it receives the data from the sender.
Recharging Current	Local	0–20 mA	Recharging Current refers to the flow of electric charge supplied to a battery during the recharging process.
Network Layer			

Continued on next page

Table 2-2: *(continued)*

Parameter	Scope	Range	Description
Routing Protocol	Global	DSR, AODV, ZRP, OLSR	AODV (Ad hoc on Demand Distance Vector) is an on-demand routing protocol for wireless networks that uses traditional routing tables to store routing information. AODV uses timers at each node and expires the routing table entry after the route is not used for a certain time. DSR (Dynamic Source Routing) is a routing protocol for wireless mesh networks. It is similar to AODV, in that it forms a route on-demand when a transmitting computer requests one. However, it uses source routing instead of relying on the routing table at each intermediate device. ZRP (Zone Routing Protocol) is a hybrid Wireless Networking routing protocol that uses both proactive and reactive routing protocols when sending information over the network. ZRP divides the entire network into zones of variable size. Every node in the network has a zone associated to it. OLSR (Optimized Link State Routing Protocol) is a proactive link-state routing protocol, which uses hello and topology control (TC) messages to discover and then disseminate link state information throughout the mobile ad hoc network.
DSR Routing Protocol			
ACK Type	Global	Link Layer ACK or Network Layer ACK	The user can enable either Link Layer ACK (Layer 2 ACK) or Network Layer ACK (Layer 3 ACK). Link Layer ACK uses MAC layer acknowledgment for route maintenance, while Network Layer ACK uses DSR acknowledgment for route maintenance. For more details, refer to sections 3.2.1 and 3.2.2 of the MANET Technology Library.
AODV Routing Protocol			
Hello Message	Global	Enable/Disable	Hello messages are periodic broadcasts used to maintain local connectivity and discover neighbors, ensuring that nodes are aware of each other's presence. Enabled: You will observe Hello packets being sent and received in the simulation. Disabled: Hello packets are not transmitted or received. Without HELLO messages, AODV's route discovery (RREQ/RREP) remains the same. However, route maintenance shifts from proactive local link sensing (via HELLO) to reactive link break detection.
ZRP and OLSR Routing Protocol			

Continued on next page

Table 2-2: *(continued)*

Parameter	Scope	Range	Description
Hello Interval	Global	1–100 s	Hello interval parameter is used for neighbor discovery process. This parameter determines how frequently Hello messages are sent out and also how frequently a neighbor table will be updated.
Refresh Interval	Global	1–100 s	Refresh interval is the duration after which each active node periodically refreshes routes to itself.
IARP	Fixed	–	Intra-zone Routing Protocol (IARP) is used by a node to communicate with the interior nodes of its zone. It proactively maintains routes to destinations within the local routing zone, limited by the zone radius.
TC Interval	Global	1–100 s	Topology Control (TC) messages are sent at the TC interval. This parameter defines how frequently TC messages are generated and exchanged to advertise topology information in the network.
Zone radius	Global	2–225 m	ZRP divides the entire network into zones. The radius of these zones is defined by the Zone radius parameter. It determines the extent of the local routing zone maintained proactively by IARP.

2.8 Run Simulation

Click on Run Simulation icon on the top toolbar.

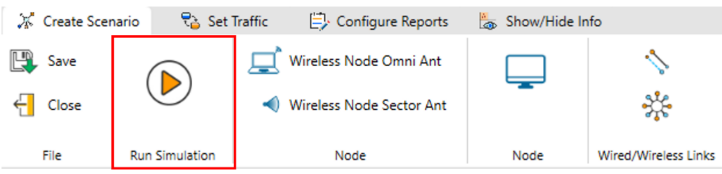


Figure 2-19: *Run Simulation option on top ribbon*

Set the Simulation Time and click on OK.

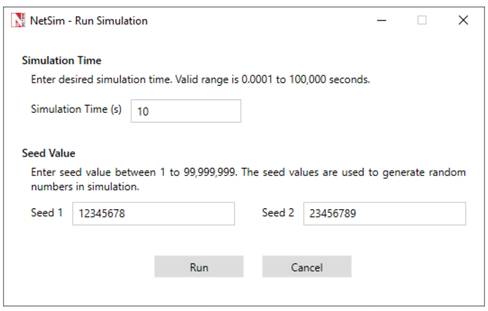


Figure 2-20: *Run Simulation window*

NOTE: MANET implementation in NetSim:

- If a user wants to implement an HTTP application among nodes, TCP must be enabled in source node as TCP is set to disable by default.

- OLSR is a proactive link-state routing protocol. It uses Hello and topology control (TC) messages to discover and then disseminate link state information throughout the mobile ad hoc network.
- Individual nodes use this topology information to compute next hop destinations for all nodes in the network using shortest hop forwarding paths. For topology control (TC) messages to disseminate throughout, it requires 5 or more seconds depending upon the network size. In general, it is (5.5 secs + Tx Time × network size).
- Hence, when simulating OLSR in MANET the Application Start Time must be greater than 5s (preferably greater than 10s) because in OLSR Topology Control (TC) messages start at 5s. Once the TC messages are sent, some further time will be required for OLSR to find the route. This can be done by setting the "Start Time" parameter in Application properties.

3 Model Features

3.1 Ad hoc On Demand Distance Vector Routing

The Ad Hoc On-Demand Distance Vector (AODV) algorithm enables dynamic, self-starting, multi-hop routing between participating mobile nodes wishing to establish and maintain an ad hoc network. AODV allows mobile nodes to respond to link breakages and changes in network topology in a timely manner. When links break, AODV causes the affected set of nodes to be notified so that they can invalidate the routes using the lost link. AODV in NetSim can run in layer 3 over MAC/PHY protocols such as 802.11, 802.15.4, TDMA and DTDMA.

The features of AODV implemented in NetSim are:

Broadcast Route Discovery Mechanism, and Route Maintenance: AODV accomplishes this with the help of RREQ and RREP. The packet trace file in NetSim helps to view and understand how AODV accomplishes this mechanism using RREQ and RREP packets.

Timer - based states: Routing table states expire when the route remains inactive for a certain period of time. This is established by the use of the lifetime field in the routing table and RREP packets. The lifetime field can be observed in Wireshark under the AODV RREP packets.

Sequence numbers: The source sequence number is a monotonically increasing number maintained by each source node. It is used by other nodes to determine whether the information contained in the packet sent by the source node is new. The destination sequence number is created by destination and includes it with the routing information sent to the requesting nodes. Usage of destination sequence number ensures loop freedom. The route with the greatest sequence number is used by requesting nodes to reach their destination. This also prevents routing loops and avoids using inactive or old routes. The source and destination sequence numbers can be viewed in Wireshark under the RREQ and RREP packets in AODV protocols. Some important fields of the RREQ format that can be viewed in NetSim using Wireshark are listed in Table 3-1 below.

Table 3-1: *Important fields of the RREQ format viewed in NetSim using Wireshark*

Field	Description
Hop Count	The number of hops from the Originator IP Address to the node handling the request.
Destination IP Address	The IP address of the destination for which a route is desired.
Destination Sequence Number	The latest sequence number received in the past by the originator for any route towards the destination.
Originator IP Address	The IP address of the node which originated the Route Request.
Originator Sequence Number	The current sequence number to be used in the route entry pointing toward the originator node.

Some important fields of the RREP format that can be viewed in NetSim using Wireshark are listed in Table 3-2 below.

Table 3-2: *Important fields of the RREP format viewed in NetSim using Wireshark*

Field	Description
Hop count	The number of hops from the Originator IP Address to the Destination IP Address.
Destination IP Address	The IP address of the destination for which a route is supplied.
Destination Sequence Number	The destination sequence number associated to the route.
Originator IP Address	The IP address of the node which sends the RREQ.
Lifetime	The time in milliseconds for which nodes receiving the RREP consider the route to be valid.

3.2 Dynamic Source Routing (DSR)

The Dynamic Source Routing (DSR) protocol is a simple and efficient routing protocol designed specifically for multi-hop wireless ad hoc networks of mobile nodes. Using DSR, the network is completely self-organizing and self-configuring, requiring no existing network infrastructure or administration.

Network nodes cooperate to forward packets for each other, enabling communication over multiple "hops" between nodes that are not directly within wireless transmission range of one another. As nodes move, join, or leave the network, and as wireless transmission conditions (e.g., interference sources) change, all routing is automatically determined and maintained by the DSR protocol.

Since the number or sequence of intermediate hops needed to reach any destination may change at any time, the resulting network topology can be dynamic and rapidly evolving.

In NetSim, DSR operates at Layer 3 over MAC/PHY protocols such as 802.11, 802.15.4, TDMA, and DTDMA.

3.2.1 Using Link-Layer Acknowledgements

If the MAC protocol in use provides feedback as to the successful delivery of a data packet (such as is provided for unicast packets by the link-layer acknowledgement frame defined by IEEE 802.11), then the use of the DSR Acknowledgement Request and Acknowledgement options is not necessary. If such link-layer feedback is available, it should be used instead of any other acknowledgement mechanism for Route Maintenance, and the node should not use either passive acknowledgements or network-layer acknowledgements for Route Maintenance.

When using link-layer acknowledgements for Route Maintenance, the retransmission timing and the timing at which retransmission attempts are scheduled are generally controlled by the particular link layer implementation in use in the network. For example, in IEEE 802.11, the link-layer acknowledgement is returned after a unicast packet as a part of the basic access method of the IEEE 802.11 Distributed Coordination Function (DCF) MAC protocol; the time at which the acknowledgement is expected to arrive and the time at which the next retransmission attempt (if necessary) will occur are controlled by the MAC protocol implementation.

3.2.2 Using Network-Layer Acknowledgements

When a node originates or forwards a packet and has no other mechanism of acknowledgement available to determine reachability of the next-hop node in the source route for Route Maintenance, that node should request a network-layer acknowledgement from that next-hop node. To do so, the node inserts an Acknowledgement Request option in the DSR Options Header in the packet. The Identification field in that Acknowledgement Request option must be set to a unique value over all packets recently transmitted by this node to the same next-hop node.

When using network-layer acknowledgements for Route Maintenance, a node should use an adaptive algorithm in determining the retransmission timeout for each transmission attempt of an acknowledgement request. For example, a node should maintain a separate round-trip time (RTT) estimate for each node to which it has recently attempted to transmit packets, and it should use this RTT estimate in setting the timeout for each retransmission attempt for Route Maintenance.

While simulating certain network configurations, users may see that packets received are more than packets sent. This is because:

- This is being measured as part of our UDP protocol metrics in layer 4 in the source and in the destination.
- Let us say UDP protocol at source node A sends a datagram. At the MAC - WLAN sends the frame and starts a retransmission timer.
- If no Ack is received within this timer period, it would initiate a re-transmission (consider cases where the WLAN Ack has a collision or is errored).
- As the destination, the MAC (WLAN) layer would send up to UDP both the first packet it received and the re-transmitted packet it received.
- UDP protocol in the destination would count both the packets received.

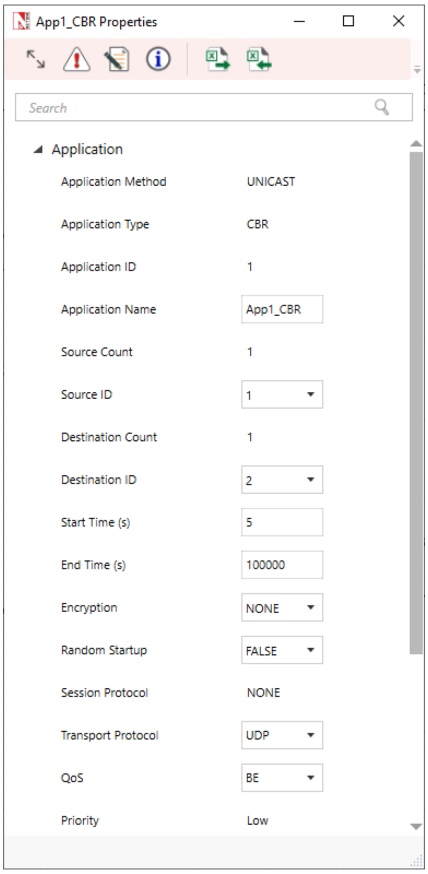


Figure 3-1: *Application Configuration window*

3.2.3 Why do we see continuous RREQ and RREP packets in DSR?

When the Data packet is to be transmitted, in DSR, within the NETWORK OUT Event, the DSR-packet-processing function is called. This initiates Route discovery, if no route to destination exists. Once discovery is complete, DSR switches to Route maintenance mode.

Route Maintenance is the mechanism by which a source node S is able to detect, while using a source route to some destination node D, if the network topology has changed such that it can no longer use its route to D because a link along the route no longer works.

In Route Maintenance mode, DSR checks for ACKs for every data packet sent. If the ACK for a data packet is not received within a specified time (as defined by the Maintenance Time Out) then Route Error (RERR) gets triggered. This trigger leads to removal of Route entries from the Route Cache thereby causing Route discovery to be initiated again.

A typical simulation scenario where Route discovery, Route Error, Route discovery cycle is repeated, is when the network has multiple applications generating data packets at the exact same time. This can cause packet collisions in the MAC layer. Since no packet is received no ACK is sent. The non-receipt of ACK within the specified time causes RERR to get triggered.

3.3 AODV/DSR Metrics

AODV or DSR Metrics table will be part of the results dashboard if routing protocol in the network layer is set to either AODV or DSR in at least one device in the simulated network scenario.

Table 3-3: *Parameter Description for AODV/DSR Metrics table*

Parameter	Description
Device Id	It is the unique ID of the wireless node
RREQ sent	It is the number of Route Request packets sent by wireless node during Route Discovery process
RREQ forwarded	It is the number of Route Request packets forwarded by wireless node during Route Discovery process
RREP sent	It is the number of Route Reply packets sent by wireless node when route is found during Route Discovery process
RREP forwarded	It is the number of Route Reply packets forwarded by a wireless node when route is found during Route Discovery process
RERR sent	It is the total number of Route Error packets sent by a wireless node during Route Maintenance
RERR forwarded	It is the total number of Route Error packets forwarded by a wireless node during Route Maintenance
Packet originated	It is the total number of packets originated in a source node
Packet transmitted	It is the total number of packets transmitted by a source node and intermediate device (LoWPAN Gateway or sink node)
Packet dropped	It is the total number of packets dropped by a wireless node

3.4 Zone Routing Protocol (ZRP)

The ZRP is based on two procedures:

1. Intrazone Routing Protocol (IARP) and
2. Interzone Routing Protocol (IERP).

Through the use of the IARP, each node learns the identity of and the (minimal) distance to all the nodes in its routing zone. The actual IARP is not specified and can include any number of protocols, such as the derivatives of Distance Vector Protocol (e.g., Ad Hoc On-Demand Distance Vector, Shortest Path First (e.g., OSPF). In fact, different portions of an ad hoc network may choose to operate based on different choices of the IARP protocol. Whatever the choice of IARP is, the protocol needs to be modified to ensure that the scope of this operation is restricted to the zone of the node in question.

Note that as each node needs to learn the distances to the nodes within its zone only, the nodes are updated about topological changes only within their routing zone. Consequently, in spite of the fact that a network can be quite large, the updates are only locally propagated.

IERP

While IARP finds routes within a zone, IERP is responsible for finding routes between nodes located at distances larger than the zone radius. IERP relies on border casting. Border casting is possible as any node knows the identity and the distance to all the nodes in its routing zone by the virtue of the IARP protocol.

The IERP operates as follows: The source node first checks whether the destination is within its routing zone. (Again, this is possible as every node knows the content of its zone). If so, the path to the destination is known and no further route discovery processing is required. If, on the other hand, the destination is not within the source's routing zone, the source border casts a route request (referred to here as a "request") to all its peripheral nodes. Now, in turn, all the peripheral nodes execute the same algorithm: check whether the destination is within their zone. If so, a route reply (referred to here as a "reply") is sent back to the source indicating the route to the destination. If not, the peripheral node forwards the query to its peripheral nodes, which, in turn, execute the same procedure. An example of this Route Discovery procedure is demonstrated in Figure 3-1 below.

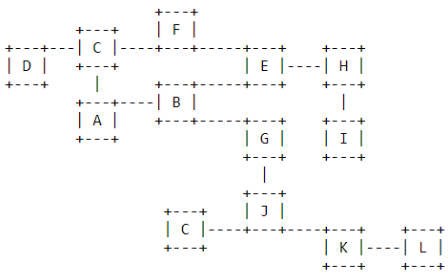


Figure 3-2: *Interzone Routing Protocol Discovery procedure*

Node A has a datagram to node L. Assume routing zone radius of 2. Since L is not in A's routing zone (which includes B, C, D, E, F, G), A bordercasts a routing request to its peripheral nodes: D, F, E, and G. Each one of these peripheral nodes check whether L exists in their routing zones. Since L is not found in any routing zones of these nodes, the nodes border cast the request to their peripheral nodes. In particular, G border casts to K, which realizes that L is in its routing zone and returns the requested route (L-K-G-A) to the query source, namely A.

IARP

In Zone Routing, the Intra zone Routing Protocol (IARP) proactively maintains routes to destinations within a local neighborhood, which we refer to as a routing zone. More precisely, a node's routing zone is defined as a collection of nodes whose minimum distance in hops from the node in question is no greater than a parameter referred to as the zone radius. Note that each node maintains its own routing zone. An important consequence is that the routing zones of neighboring nodes overlap.

An example of a routing zone (for node A) of radius 2 is shown in Figure 3-2 below.

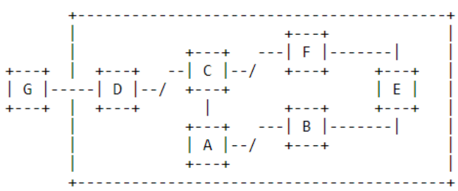


Figure 3-3: *Intra zone Routing Protocol Discovery procedure*

In this example, nodes B through F are within the routing zone of node A, while node G is outside node A's routing zone. Node E can be reached via two paths from A: one with a length of 2 hops and the other with a length of 3 hops. Since the minimum hop count is less than or equal to 2, E is included in A's routing zone.

Peripheral Nodes are nodes whose minimum distance to a given node is exactly equal to the zone radius. Thus, in the example above, nodes D, F, and E are the peripheral nodes of node A.

To construct a routing zone, a node must first identify its neighbors. A neighbor is a node with which direct (point-to-point) communication can be established and is, therefore, one hop away. Neighbor identification can be provided by MAC protocols, such as in polling-based protocols, or by a separate Neighbor Discovery Protocol (NDP).

Neighbor discovery typically involves the periodic broadcasting of "HELLO" beacons. The reception (or quality of reception) of these beacons is used to determine the status of the connection to the beaconing neighbor.

This neighbor discovery information forms the basis of the Intra zone Routing Protocol (IARP). IARP can be derived from globally proactive link-state routing protocols that offer a complete view of network connectivity.

3.5 Optimized Link State Routing Protocol (OLSR)

OLSR is developed for mobile ad hoc networks. It operates as a table driven, proactive protocol, i.e., exchanges topology information with other nodes of the network regularly. Each node selects a set of its neighbor nodes as "multipoint relays" (MPR). In OLSR, only nodes, selected as such MPRs, are 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 for declaring link state information in the network. Indeed, the only requirement for OLSR 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, e.g., for redundancy.

Nodes which have been selected as multipoint relays by some neighbor node(s) announce this information periodically in their control messages. This allows a node to announce to the network that it has reachability to the nodes which have selected it as an MPR. In route calculation, MPRs are used to form the route from a given node to any destination in the network. Furthermore, the protocol uses the MPRs to facilitate efficient flooding of control messages in the network.

3.5.1 One Hop neighbor

Node X is considered a neighbor of node Y when node Y is within communication range of node X, meaning there is an established link between OLSR interfaces on both nodes that enables direct communication.

3.5.2 Two Hop neighbor

A 2-hop neighbor of node X is a node that is not directly connected to X, but is connected to one of X's direct neighbors.

3.5.3 Multipoint Relays (MPR)

Multipoint Relays (MPRs) are a smart technique used to reduce the number of broadcast messages in a wireless network. Normally, when a node sends out a broadcast message (like link information), all its neighbors may forward it again, which creates a lot of unnecessary traffic and wastes bandwidth. MPRs solve this by selecting only a few special neighbors to forward those messages.

Each node chooses some of its 1-hop neighbors as its MPRs. These MPRs are chosen in such a way that they can reach all the 2-hop neighbors. This means fewer nodes need to retransmit the message to spread it across the network.

The chosen MPR nodes will forward broadcast messages from that node.

The rest of the neighbors receive the message but do not retransmit it.

This reduces the number of duplicate messages in the network and saves battery and bandwidth.

Also, each node keeps track of which neighbors have selected it as their MPR, using the HELLO messages that are exchanged regularly.

3.5.4 Topology discovery

The link-sensing and neighbor-detection parts of the protocol provide each node with a list of neighbors it can directly communicate with. Combined with the Packet Format and Forwarding part, this enables an optimized flooding mechanism through MPRs. Using this, topology information is disseminated throughout the network.

3.5.5 TC Message Format

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              ANSN             |           Reserved            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|               Advertised Neighbor Main Address                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|               Advertised Neighbor Main Address                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                              ...                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 3-4: *TC Message Format*

The TC message consists of the following fields:

ANSN (Advertised Neighbor Sequence Number):

- A 16-bit field used to indicate the freshness of the TC information.

Reserved:

- A 16-bit field reserved for future use; always set to 0.

Advertised Neighbor Main Addresses:

- These are one or more addresses of the neighboring nodes that the sender can reach and wants to inform others about. Usually, these are the nodes that have selected the sender as their MPR.

3.5.6 Core Functionality of OLSR

OLSR's core working is made up of several key parts:

Packet Format and Forwarding

All control messages (like HELLO, TC, etc.) follow a common packet format.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Packet Length         |    Packet Sequence Number     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Message Type |     Vtime     |         Message Size          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Originator Address                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Time To Live |   Hop Count   |    Message Sequence Number    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
:                            MESSAGE                            :
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Message Type |     Vtime     |         Message Size          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Originator Address                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Time To Live |   Hop Count   |    Message Sequence Number    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
:                            MESSAGE                            :
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
:                                                               :
         (etc.)
```

Figure 3-5: *Packet Format*

OLSR uses a smart way to flood (send to all nodes) control messages across the network using a technique called MPR (MultiPoint Relay) to reduce unnecessary retransmissions.

3.5.7 Link Sensing

Each node sends HELLO messages at regular intervals through its network interfaces.

These messages help a node detect which of its neighbors are reachable (link sensing).

This creates a local link set—a list of links to neighboring nodes.

3.5.8 Neighbor detection

Neighbor detection populates the neighborhood information base and concerns itself with nodes and node main addresses. The mechanism for neighbor detection is the periodic exchange of HELLO messages.

A node maintains a set of neighbor tuples based on the link tuples. This information is updated according to changes in the Link Set. The Link Set keeps the information about the links, while the Neighbor Set keeps the information about the neighbors. There is a clear association between those two sets, since a node is a neighbor of another node if and only if there is at least one link between the two nodes.

The "Originator Address" of a HELLO message is the main address of the node that emitted the message. Upon receiving a HELLO message, a node should first update its Link Set and then update its Neighbor Set.

3.5.9 MPR Selection

Each node selects a few special neighbors called MPRs (MultiPoint Relays).

These MPRs are chosen in such a way that if they forward a message, it will reach all 2-hop neighbors (neighbors of neighbors).

This reduces the number of transmissions during flooding.

Nodes advertise their selected MPRs in their HELLO messages.

3.5.10 TC message

In order to build the topology information base, each node, which has been selected as MPR, broadcasts Topology Control (TC) messages. TC messages are flooded to all nodes in the network and take advantage of MPRs. MPRs enable a better scalability in the distribution of topology information.

The list of addresses can be partial in each TC message (e.g., due to message size limitations, imposed by the network), but parsing of all TC messages describing the advertised link set of a node MUST be complete within a certain refreshing period (TC INTERVAL). The information diffused in the network by these TC messages will help each node calculate its routing table.

When the advertised link set of a node becomes empty, this node SHOULD still send (empty) TC-messages during the duration equal to the "validity time" (typically, this will be equal to TOP HOLD TIME) of its previously emitted TC-messages, in order to invalidate the previous TC-messages. It SHOULD then stop sending TC-messages until some node is inserted in its advertised link set.

A node MAY transmit additional TC-messages to increase its reactiveness to link failures. When a change to the MPR selector set is detected and this change can be attributed to a link failure, a TC-message SHOULD be transmitted after an interval shorter than TC INTERVAL.

3.5.11 Route Calculation

After collecting enough link information through HELLO and TC messages, each node calculates the best route to all other nodes.

This is usually done using shortest-path algorithms like Dijkstra which finds the minimum-cost path from the source node to all other nodes based on the link metrics (e.g., hop count, ETX).

3.6 Optimized Link State Routing Protocol Version 2 (OLSRv2)

The Optimized Link State Routing Protocol Version 2 (OLSRv2) is a proactive link-state routing protocol designed specifically for Mobile Ad Hoc Networks (MANETs). It is the successor to the original OLSR protocol defined in RFC 3626 and introduces several improvements to enhance routing efficiency and scalability.

OLSRv2 retains the fundamental principles of OLSR while introducing major enhancements such as support for link metrics beyond hop count and simplified message structures.

3.6.1 Evolution from OLSR Version 1

OLSRv2 builds upon OLSR with the following key improvements:

- Support for advanced link metrics instead of simple hop count
- More flexible and efficient message encoding
- Reduced control message overhead

These improvements make OLSRv2 more suitable for dynamic and large-scale wireless networks.

Before understanding OLSRv2, it is essential to understand the protocol on which it is built, namely the Neighbor Discovery Protocol (NHDP). OLSRv2 does not perform neighbor discovery by itself; instead, it relies on NHDP to provide accurate and up-to-date information about neighboring nodes and link conditions.

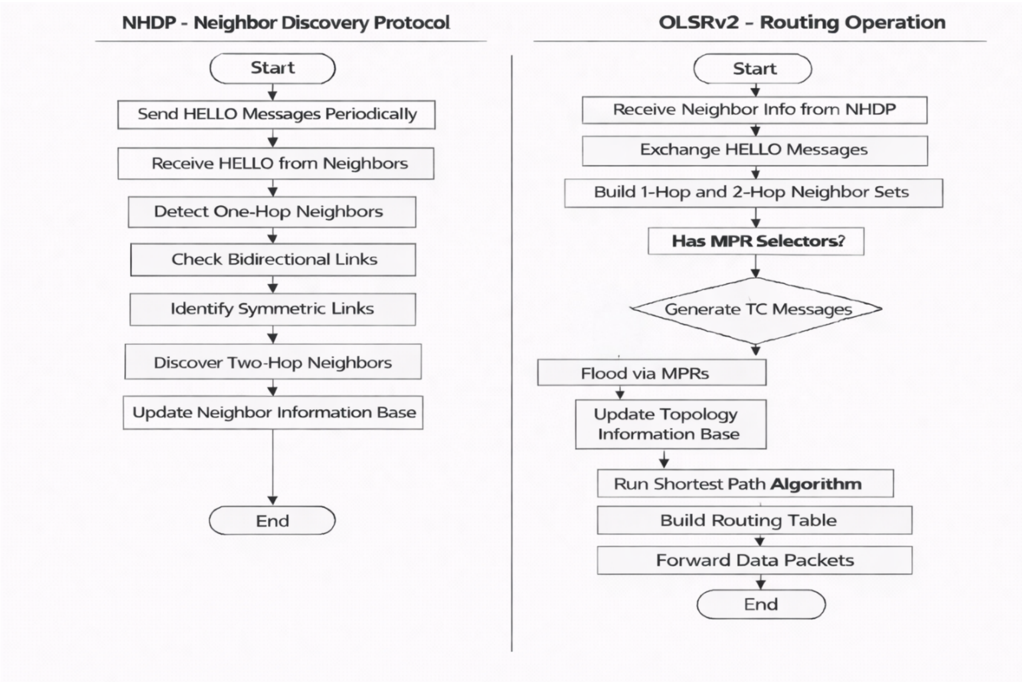


Figure 3-6: *NHDP and OLSRv2 Working Flow Diagram*

3.6.2 NHDP – Neighbor Discovery Protocol

Overview

The Neighbor Discovery Protocol (NHDP) is designed to discover and maintain information about neighboring nodes in a Mobile Ad Hoc Network. It operates through periodic exchange of local HELLO messages, allowing each node to determine the presence, connectivity, and link characteristics of its neighbors.

NHDP enables nodes to identify both:

- One-hop neighbors (directly reachable nodes)
- Symmetric two-hop neighbors (nodes reachable through one intermediate neighbor)

NHDP messages are formatted and transmitted using the standardized MANET packet format defined in RFC 5444.

Objectives of NHDP

The primary objective of NHDP is to maintain accurate and up-to-date information about local network connectivity in a dynamic wireless environment.

Specifically, NHDP performs the following functions:

- Detects directly reachable one-hop neighbors
- Identifies symmetric two-hop neighbors
- Verifies bidirectional communication links
- Tracks link establishment and failures
- Maintains updated neighbor information over time

NHDP Information Bases

NHDP maintains structured data repositories known as Information Bases, which store neighbor and link information. These databases provide essential inputs to MANET routing protocols such as OLSRv2 and are continuously updated based on received HELLO messages.

Link Quality and Hysteresis

NHDP uses a link quality mechanism to determine whether a link between two nodes should be considered usable or unreliable. Instead of immediately accepting or rejecting a link, the protocol evaluates the quality of the link using hysteresis thresholds.

The following interface parameters are:

HYST_ACCEPT – The link quality threshold at or above which a link becomes usable.

HYST_REJECT – The link quality threshold below which a link becomes unusable.

INITIAL_QUALITY – The initial quality value assigned to a newly identified link.

INITIAL_PENDING – If set to true, a newly identified link is considered pending and is not usable until the link quality reaches or exceeds the HYST_ACCEPT threshold.

Parameter Constraints:

$0 \leq \text{HYST\_REJECT} \leq \text{HYST\_ACCEPT} \leq 1$

$0 \leq \text{INITIAL\_QUALITY} \leq 1$

If link quality is not updated, then $\text{INITIAL\_QUALITY} \geq \text{HYST\_ACCEPT}$.

If $\text{INITIAL\_QUALITY} \geq \text{HYST\_ACCEPT}$, then $\text{INITIAL\_PENDING} = \text{false}$.

If $\text{INITIAL\_QUALITY} < \text{HYST\_REJECT}$, then $\text{INITIAL\_PENDING} = \text{true}$.

One-Hop and Two-Hop Neighbor Discovery

NHDP discovers neighboring nodes through periodic HELLO message exchanges.

- When a node receives a HELLO message, it records the sender as a one-hop neighbor.
- Initially, the link is considered unidirectional.
- The link becomes symmetric when both nodes report each other.

Two-hop neighbors are discovered indirectly through neighbor information included in HELLO messages. When a node receives a HELLO message containing the addresses of another node's neighbors, it identifies those nodes as two-hop neighbors reachable through the intermediate node.

Thus, NHDP continuously maintains updated information about one-hop and two-hop neighboring nodes, enabling routing protocols to accurately understand local network topology.

Generalized MANET Packet Format

The generalized MANET packet format defines a standardized method for exchanging routing information in MANETs. It allows multiple protocol messages to be carried within a single packet transmission, improving efficiency.

The format uses:

- Address Blocks for compact representation
- Type-Length-Value (TLV) structures for flexibility

3.6.3 Message Structure

A message consists of two main parts:

- Message Header
- Message Body

The Message Header contains control information, while the Message Body carries protocol-specific data.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Message Type  |1|1|1|1|  MAL  |          Message Size         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Originator Address                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Hop Limit   |   Hop Count   |    Message Sequence Number    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                         Message Body                          |
|                                                               |
|                               +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 3-7: *Generalized MANET Message Structure*

3.6.4 Message Header Fields

The Message Header includes:

- Message Type
- Message Size
- Originator Address
- Hop Limit
- Hop Count
- Message Sequence Number

3.6.5 Address Blocks and TLVs

Address Blocks allow multiple addresses to be represented efficiently. Each Address Block may include TLVs describing link status, link quality, and neighbor attributes.

3.6.6 Message Body Structure

The Message Body begins with a Message TLV Block followed by pairs of Address Blocks and Address TLV Blocks containing routing information.

3.7 OLSRv2 – Protocol

OLSRv2 operates by maintaining network topology information to proactively compute routes to all known destinations.

Its operation is based on two frameworks:

Neighbor Discovery using NHDP

Message Formatting using RFC 5444

3.7.1 Protocol Overview

The main efficiency of OLSRv2 comes from Multipoint Relays (MPRs).

Types of MPRs

Flooding MPRs: A node selects a subset of its symmetric one-hop neighbors as Flooding MPRs. These are the only neighbors allowed to retransmit its broadcast control messages. This creates an efficient, reduced flooding mechanism that minimizes overhead while ensuring messages are disseminated throughout the network.

Routing MPRs (MPR Selectors): A node maintains a set of neighbors that have selected it as an MPR. These are known as its MPR selectors. In OLSRv2, only the links to these MPR selectors are advertised by a node in its Topology Control (TC) messages. This is a second major optimization, as it significantly reduces the amount of topological information that must be flooded.

3.7.2 Control Messages

OLSRv2 uses two primary control messages:

HELLO Messages

Exchanged periodically and locally between neighboring nodes. They are responsible for link sensing, neighbor discovery, and signaling MPR selections. The information obtained from HELLO messages populates the Interface Information Base and Neighbor Information Base.

Topology Control (TC) Messages

Generated periodically only by nodes that have at least one MPR selector (i.e., nodes that have been selected as an MPR by one or more neighbors). These messages are flooded throughout the entire network using Flooding MPRs. TC messages contain the node's MPR selector set, effectively declaring the links that form the network topology. The information from TC messages populates the Topology Information Base.

OLSRv2 Information Bases

OLSRv2 maintains the following information bases:

- Local Information Base
- Interface Information Base
- Neighbor Information Base
- Topology Information Base
- Routing Set
- Received Message Information Base

3.7.3 Control Message Details

HELLO Messages

HELLO messages are generated periodically and include:

- Local addresses
- Neighbor status information
- Link metrics

TC Messages

TC messages are generated by nodes having at least one MPR selector. They contain:

- Originator address
- Advertised neighbor set
- Validity time

MPR Selection

Selecting MPRs

The goal is to select a minimal set of one-hop neighbors such that all symmetric two-hop neighbors are reachable.

Selection depends on:

- Link symmetry
- Willingness
- Link metrics

3.7.4 Configuring OLSRv2 in NetSim

Selecting OLSRv2 as Routing Protocol

To enable OLSRv2 in NetSim:

1. Open the network scenario in NetSim.
2. Right-click on a wireless node.
3. Select Properties to open the Node Properties window.
4. Navigate to the Network Layer section.
5. Locate the Routing Protocol dropdown.
6. Select OLSRv2.

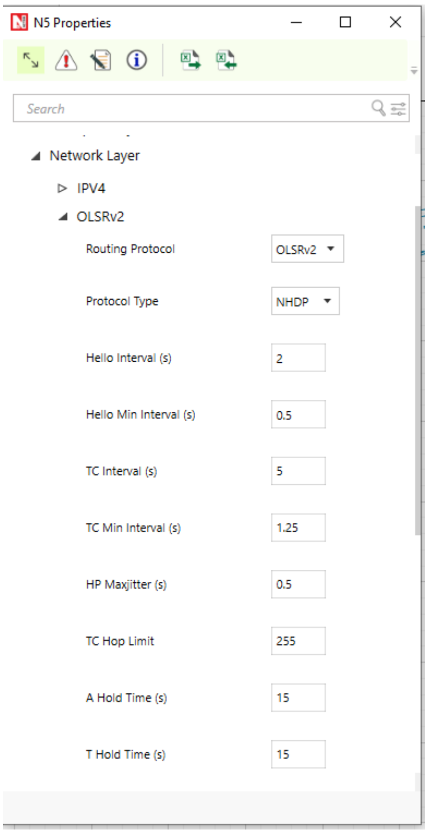


Figure 3-8: *Selecting OLSRv2 in Node Properties*

Configuring OLSRv2 Parameters

After selecting OLSRv2 as the routing protocol, several protocol parameters can be configured in NetSim to control neighbor discovery, topology dissemination, and link quality evaluation.

HELLO Message Parameters

Hello Interval (Default: 2 seconds)
Defines the time interval between consecutive HELLO message transmissions. A smaller value allows faster neighbor detection but increases control overhead.

Hello Minimum Interval – hello_min_interval (Default: 0.5 second)
Specifies the minimum allowed time between two HELLO message transmissions.

Maximum HELLO Jitter – HP_Maxjitter (Default: 0.5 seconds)
Introduces a small random delay before transmitting HELLO messages to avoid synchronization of transmissions among nodes.

Link Quality and Hysteresis Parameters

Link Quality Mode (Default: Disabled / Hop-count based routing)
Enables the use of link quality metrics instead of hop-count metrics.

Initial Quality – INITIAL_QUALITY (Default: 1.0)
Defines the starting quality value assigned to a newly detected link before sufficient observations are made.

Hyst Accept – hyst_accept (Default: 0.8)
Threshold above which the link becomes usable.

Hyst Reject – hyst_reject (Default: 0.3)
Threshold below which the link becomes unusable.

Initial Pending – INITIAL_PENDING (Default: false)
Represents the initial pending state used in link-quality calculations before the link state becomes stable.

Topology Control (TC) Parameters

TC Interval – tc_interval (Default: 5 seconds)
Defines how frequently Topology Control messages are generated.

TC Minimum Interval – tc_min_interval (Default: 1.25 seconds)
Specifies the minimum time between two TC transmissions.

Maximum TC Jitter – TP_maxjitter (Default: 0.5 seconds)
Random delay applied before TC message transmission to reduce collisions.

TC Hop Limit – tc_hop_limit (Default: 255)
Defines the maximum number of hops a TC message can travel in the network.

Information Base Hold Times

Topology Hold Time – T_hold_time (Default: 15 seconds)
Specifies how long topology information received from TC messages remains valid.

Advertised Neighbor Hold Time – A_hold_time (Default: 15 seconds)
Defines how long advertised neighbor information is retained in the topology database.

MPR and Routing Parameters

Willingness (Flooding and Routing Willingness) (Default: WILL_DEFAULT = 7)
Indicates a node's readiness to act as a Multipoint Relay (MPR). Higher willingness increases the probability of being selected as an MPR.

Configuring Wireless Link Properties

Since OLSRv2 relies on neighbor discovery, configuring wireless range is essential.

Steps:

1. Right-click on the wireless link.
2. Select Properties.
3. Under Medium Property, configure:
    - Channel Characteristics: Pathloss
    - Pathloss Model: Range Based
    - Range (m): Set as required

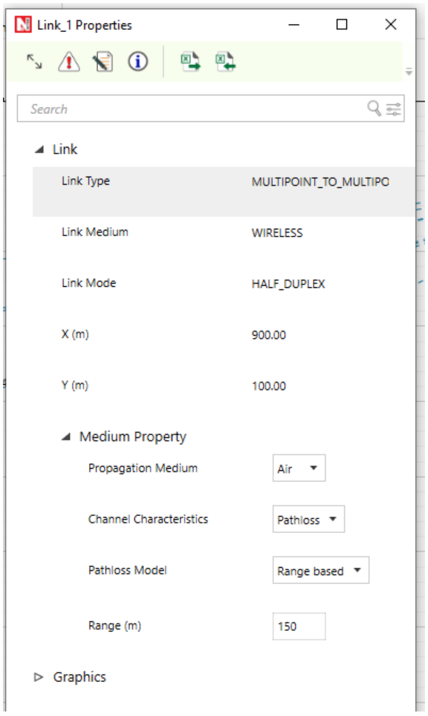


Figure 3-9: *Wireless Link Configuration for OLSRv2*

3.8 Energy model in MANETs

A Mobile Ad-hoc Network (MANET) consists of self-organizing wireless mobile nodes deployed without a centralized infrastructure. Nodes communicate with each other using a limited battery supply. NetSim supports DSR, AODV, ZRP, and OLSR as the network layer protocols, considering transmission power and residual battery power. This work aims to increase the network lifetime while reducing energy consumption and minimizing end-to-end delay.

Energy is a very important part in ad-hoc networks because all nodes in this network communicate with each other, consuming power in the process. The primary source of power is the battery of the mobile node. A node consumes energy in various modes, including sending/transmitting mode, receiving mode, and idle mode.

Transmitting mode: In this Tx mode, the node consumes energy to transfer packets or data. The amount of energy consumed in this mode depends on the number of packets sent by the node; the greater the number of packets, the more energy is consumed.

Receiving mode: In the Rx mode, the node actively listens for incoming data, consuming energy as it receives data from the sender.

Idle mode: In idle mode, a node neither transmits nor receives data packets. However, it still needs to listen to the wireless medium for potential packet reception and check for the addition of any new nodes to the network. As a result, the energy consumed in idle mode is less than that consumed in transmitting or receiving mode, since no actual communication occurs during idle mode.

In NetSim, default energy model settings are as follows:

- Transmitting current (mA): 316.7
- Receiving current (mA): 261.1
- Idle mode current (mA): 227
- Voltage (V): 3.6

The power model is disabled by default. It can be enabled in physical layer of wireless node Omni Ant.

Click on a wireless node's properties to open the right-side property panel, then navigate to Interface 1(Wireless) ▷ Physical layer.

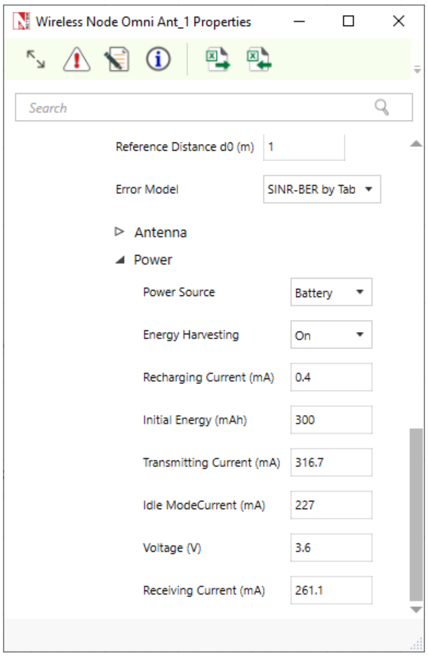


Figure 3-10: *Power Model in MANET.*

3.9 Mobility models in NetSim

The change in position of a user over time can be configured using mobility models. Such models are frequently used in simulation to evaluate the performance of mobile wireless systems. The mobility models available in NetSim are:

3.9.1 Random Walk Mobility Model

This is a simple mobility model based on random directions and speeds. In this mobility model, a mobile node moves from its current location to a new location by randomly choosing a direction. The speed can be set in the GUI. The calculation interval determines how often a new choice is made. For example, a 1s calculation interval means that a new position is chosen every 1s.

3.9.2 Random Waypoint Mobility Model

This model includes pause time between changes in direction and/or speed. A mobile node begins by staying in one location for a certain period of time (i.e., a pause time). Once this time expires, the mobile node chooses a random destination in the simulation area. The mobile node then travels toward the newly chosen destination at the selected speed. Upon arrival, the mobile node pauses for a specified PauseTime before starting the process again. Note that the movement calculation is done every Calculation Interval. Therefore, it is recommended to set the PauseTime as an integral multiple of Calculation Interval.

3.9.3 Group Mobility Model

This model describes the behavior of mobile nodes as they move together, i.e., the devices having common group id will move together.

3.9.4 Pedestrian Mobility Model

This model is applicable to each node (local parameter), and the configuration parameters are:

- Pedestrian Max Speed (m/s) (Range: 0.0 to 10.0. Default: 3.0)
- Pedestrian Min Speed (m/s) (Range: 0.0 to 10.0. Default: 1.0)
- Pedestrian stop probability (Range: 0 to 1)
- Pedestrian stop duration (s). (Range: 1 to 10000)

In this model it is assumed that the pedestrian stops at traffic lights. The stop probability represents the probability of encountering a traffic light. This is checked for every calculation interval. Once stopped, the pedestrian waits for a duration equal to stop duration for the light to turn green. A new direction is chosen randomly after every stop with θ (angle between new direction and current direction) taking values of 0, 90, 180, 270. These θ values represent the pedestrians continuing in the same direction, taking a left, making a U-turn, and taking a right, respectively.

A new speed is chosen randomly after event stop. Min speed $\leq$ Speed $\leq$ Max speed

The maximum number of stops and starts is 10.

3.9.5 File Based Mobility Model

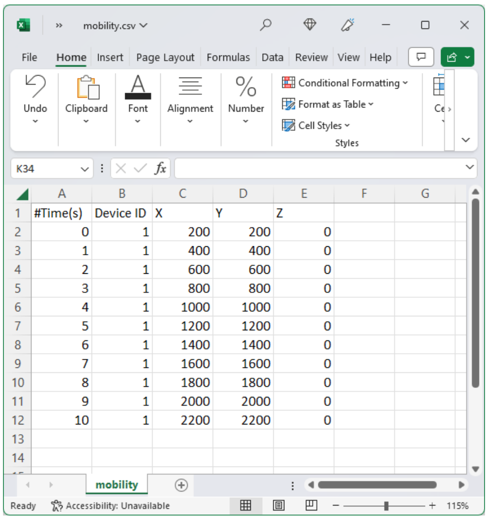
In the File Based Mobility model, users can write their own custom mobility models and define the movement of the mobile users. The content should be per the NetSim Mobility File Format explained below. Users can also generate the mobility files using external tools like SUMO (Simulation of Urban Mobility), VanetMobiSim etc.

The NetSim Mobility File setting and format is explained below:

Step 1: Right click to open Properties as a new window of Wireless Node (MANET) or UE (LTE Networks). Then properties ▷ Position Properties ▷ Mobility model as File Based Mobility and click on Open Mobility file.

Step 2: Open the CSV file and write the node mobility in the format shown below.

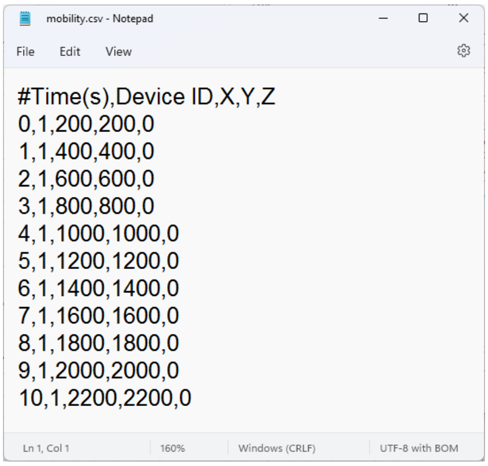
```
<TIME IN SECONDS>,<DEVICE ID>,X,Y,Z
```



#Time(s)	Device ID	X	Y	Z
0	1	200	200	0
1	1	400	400	0
2	1	600	600	0
3	1	800	800	0
4	1	1000	1000	0
5	1	1200	1200	0
6	1	1400	1400	0
7	1	1600	1600	0
8	1	1800	1800	0
9	1	2000	2000	0
10	1	2200	2200	0

Figure 3-11: *Mobility.csv file with inputs added via MS Excel*

When using spreadsheet software commas (,) are included automatically between the entries in each column. When using text editors such as notepad, users will have to manually include comma (,) between each entry.



mobility.csv - Notepad
File Edit View

#Time(s),Device ID,X,Y,Z
0,1,200,200,0
1,1,400,400,0
2,1,600,600,0
3,1,800,800,0
4,1,1000,1000,0
5,1,1200,1200,0
6,1,1400,1400,0
7,1,1600,1600,0
8,1,1800,1800,0
9,1,2000,2000,0
10,1,2200,2200,0

Ln 1, Col 1 160% Windows (CRLF) UTF-8 with BOM

Figure 3-12: *Mobility.csv file with comma separated inputs added via text editor (notepad)*

To write comments, use # tag

Specify the new location of the specific device at the specific time

Simulations with older input format in mobility.txt file (as shown below) will continue to be supported, in the absence of mobility.csv file.

$time <Time in seconds> ‘‘$node_(<NodeID - 1>) <X Coordinate> <Y Coordinate> <Z Coordinate>’’

Example: $time 1 ‘‘$node_(0) 400 400 0’’

A sample file-based mobility example is present at <NetSim Installed Directory>\Docs\ Sample Configuration\ MANET.

It can have the coordinates of one node over time, followed by the coordinates of the next node over time and so on. However, for a given device, the entries in the file need to be in increasing order of time.

NetSim does not interpolate device mobility between two entries in the mobility file. This means that during the simulation the device “jumps” to the next point at that instant in time. Mobility is not “continuous” from one point to another over time. Continuous or fine-grained mobility can, however, be approximated by reducing the time interval between successive entries. Since Excel-based mobility files are supported, generating such fine-grained traces is straightforward.

3.10 Omni and sector (directional) antennas

NetSim MANET supports Omni and sector antennas. These antenna patterns are defined by gain values that vary as a function of direction in three dimensions. Thus, a transmitter’s antenna provides a gain value with respect to every other point in space. The same is true of a receiver’s antenna. For a given transmission, the gains of both the transmitter and receiver, with respect to each other, are considered.

Omni directional antennas have an isotropic pattern i.e., the gain in all directions is 0 dB. This makes them well-suited for scenarios where uniform coverage is required in all directions.

Sector antennas are modeled per the standard 2D parabolic antenna. The key characteristic of a sector antenna is its horizontal radiation pattern, which is designed to focus the signal in a specific direction. This directional pattern allows for targeted coverage, making sector antennas ideal for applications that require directed communication over a particular sector of space. The horizontal radiation pattern of a sector antenna is given by

$$A_{E,H}(\varphi) = -\min\left(12\left(\frac{\varphi}{\varphi_{3\text{dB}}}\right)^2, A_m\right) \quad (1)$$

where,

- A_m is the front to back ratio (i.e., the ratio of power gained between the front and rear of a directional antenna). This is a user input with a default setting of 30 dB.
- φ is the angle formed between the direction of interest (i.e., the line connecting the transmitter and the receiver) and the antenna's boresight direction (azimuth angle).
- $\varphi_{3\text{dB}}$ is the 3 dB, or half power, beam width of the antenna.

The sector antenna gain is given by the expression.

$$A_E(\varphi,\theta) = G_{E,\max} - \min\{-[A_{E,H}(\varphi) + A_{E,V}(\theta)],\ A_m\} \tag{2}$$

where,

- $A_{E,V}(\theta)$ is currently 0 dB, and is a parameter reserved for future use to include the vertical radiation pattern of the antenna, and
- $G_{E,\max}$ is the maximum directional gain of the radiation element (in dB) i.e., the gain along the antenna boresight; this parameter is a user input, and the default value is 8 dBi.

The boresight angle denotes the azimuthal direction of maximum gain, or the highest radiated power, and is a user input. This can vary from 0 to 360 degrees.

Angle in NetSim is defined to start at 0 from the positive X-axis. In the network scenario, if positive Y points downward, the angle increases on clockwise rotation from the positive X-axis. If positive Y points upward, the angle increases in an anti-clockwise direction from the positive X-axis. The unit for angle is degrees.

The gain computations for a transmitter-receiver pair are given below.

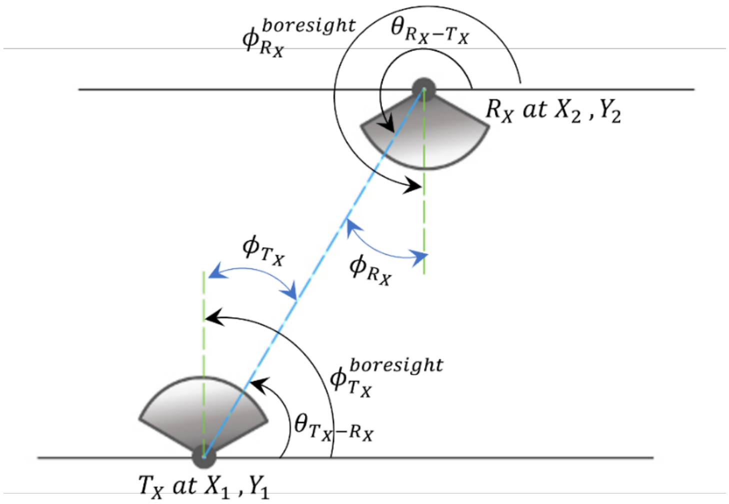


Figure 3-13: *The illustration shows a transmitter at X_1, Y_1 and a receiver at X_2, Y_2. The green lines represent the boresight azimuth direction of each antenna. The blue line is the line joining the transmitter and the receiver. ϕ_{tx} (and ϕ_{Rx}) are the angles formed between the line connecting the transmitter and the receiver and the transmit antennas (and receive antennas respectively) boresight direction.*

Let the transmitter be at X_1, Y_1 and the receiver at X_2, Y_2. Let $\phi_{T_X}^{\text{boresight}}$ and $\phi_{R_X}^{\text{boresight}}$ be the boresight azimuth angles of the transmitter and the receiver configured by the user through the GUI.

We know that,

$$\theta_{T_X-R_X} = \tan^{-1}\left(\frac{y_2-y_1}{x_2-x_1}\right) \tag{3}$$

and clearly,

$$\theta_{R_X-T_X} = \pi + \theta_{T_X-R_X} \tag{4}$$

$$\phi_{T_X} = \phi_{T_X}^{\text{boresight}} - \theta_{T_X - R_X} \tag{5}$$

$$\phi_{R_X} = \phi_{R_X}^{\text{boresight}} - \theta_{R_X - T_X} \tag{6}$$

The sign of ϕ_{T_X} or ϕ_{R_X} doesn't matter since the square of the term is used in the gain calculations.

$$A_{T_X}(\phi) = -\min\left[12\left(\frac{\phi_{T_X}}{\varphi_{3\text{dB}}}\right)^2,\ A_m\right] \tag{7}$$

$$A_{R_X}(\phi) = -\min\left[12\left(\frac{\phi_{R_X}}{\varphi_{3\text{dB}}}\right)^2,\ A_m\right] \tag{8}$$

$$T_X\ \text{Gain} = G_{E,\max} - \min[-A_{T_X}(\phi),\ A_m] \tag{9}$$

$$R_X\ \text{Gain} = G_{E,\max} - \min[-A_{R_X}(\phi),\ A_m] \tag{10}$$

Enabling the radio measurements log allows for the visualization of transmit and receive antenna gains for each transmission.

3.10.1 Limitations

- The vertical radiation pattern is not currently supported. Hence the horizontal radiation pattern is assumed to be valid for all values of the coordinate z.

3.11 How are packet collisions modelled in NetSim?

Packet Collision is a theoretical concept. In the real world, a packet is not a "physical" entity that can collide. Therefore, a "collision" is the interference of two radio waves (of the packets being sent).

In NetSim the collision model is as follows:

- At the transmitter, when a packet is being transmitted, if the sum of received power from all other nodes is greater than the receiver sensitivity then that packet is marked as collided.
- At the receiver, when a packet is being received, if the sum of the received power from all other nodes, except the node from where this packet is being transmitted, is greater than the receiver sensitivity then that packet is marked as collided.
- There is also a special case where a single packet can be marked as collided as explained in Figure 3-3.

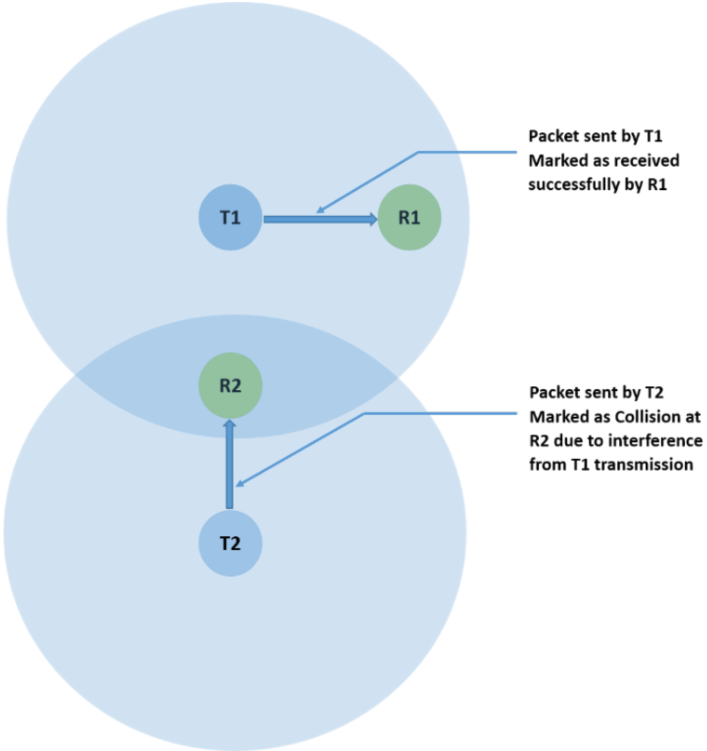


Figure 3-14: *Packet collisions modelled.*

Where,

- T1 and T2 are transmitters.
- R1 and R2 are receivers.

3.12 How is packet error decided in NetSim

The way the packet error is decided is given as follows:

- Compute Rx power at the receiver based on Tx Power, fewer losses due to Propagation. Propagation models cover HATA Urban, Sub Urban, COST 231 HATA, Indoor Home / Office, Factory, Lognormal, Free space. Apart from path loss, fading and shadowing can also be modeled.
- Rx Power / (Background Noise + Interference noise) = SINR. Here Interference noise is due to other transmissions within the network.
- Based on the SINR, BER is got from the respective modulation curve/table.
- Based on the BER, the packet error rate is decided.
- NetSim does not perform bitwise simulation since it would be too computationally intensive.

3.13 Broadcast in MANETs

In MANET, only neighbor (nodes within transmission range) broadcast is supported; multi-hop broadcast is not supported. This means that nodes that are 2-hops or more away will not receive the broadcast packets. The reason for not implementing a multi-hop broadcast is explained below.

The simplest form of broadcast in an ad hoc network is where a node transmits a broadcast packet, which is received by all neighboring nodes that are within transmission range. Upon receiving a broadcast packet, each node determines if it has transmitted the packet before. If not, then the packet is retransmitted.

This process allows for a broadcast packet to be disseminated throughout the ad hoc network. The process terminates when all nodes have received and transmitted the packet being broadcast at least once.

This method of broadcasting is required given the dynamic nature of ad hoc networks, i.e., nodes move around, and neighbors may change as the broadcast is happening. Now, since all nodes participate in the broadcast, it causes flooding and hence suffers from the Broadcast Storm Problem. Flooding is extremely costly and leaves the network completely congested.

Special algorithms are required to alleviate the broadcast storm problem, and custom development is necessary to implement them.

3.14 Radio measurement log file and plots

NetSim IEEE 802.11 Radio Measurements log file records pathloss, shadowing loss, fading loss, received power, transmitted power, SNR, and BER. This log can be enabled by clicking on configure reports in top ribbon ▷ Plots ▷ Select IEEE 802.11 Radio Measurements log under Network Logs as shown below

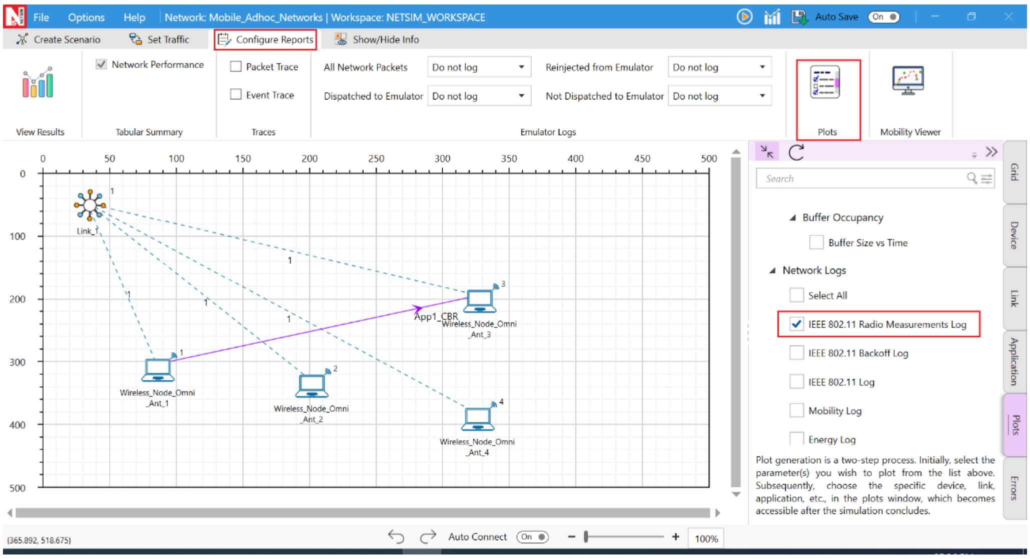


Figure 3-15: *Enabling the IEEE 802.11 Radio Measurements log*

The IEEE802.11 Radio Measurements log.csv file will contain the following information:

- Time in Milliseconds
- Transmitter Name
- Receiver Name
- Distance between the Transmitter and the Receiver in meters
- Packet ID
- Packet Type
- Control Packet Type
- Transmitter Power in dBm
- Pathloss in dB
- Shadowing Loss in dB
- Fading Loss in dB
- Total Loss in dB
- Transmitter Antenna Gain in dB

- Receiver Antenna Gain in dB
- Received Power in dBm
- Interference in dBm
- SNR in dB
- SINR in dB
- BER
- NSS (Number of Spatial Streams)
- MCS Index
- The log file can be accessed from the Simulations Results Window under the log as shown below.

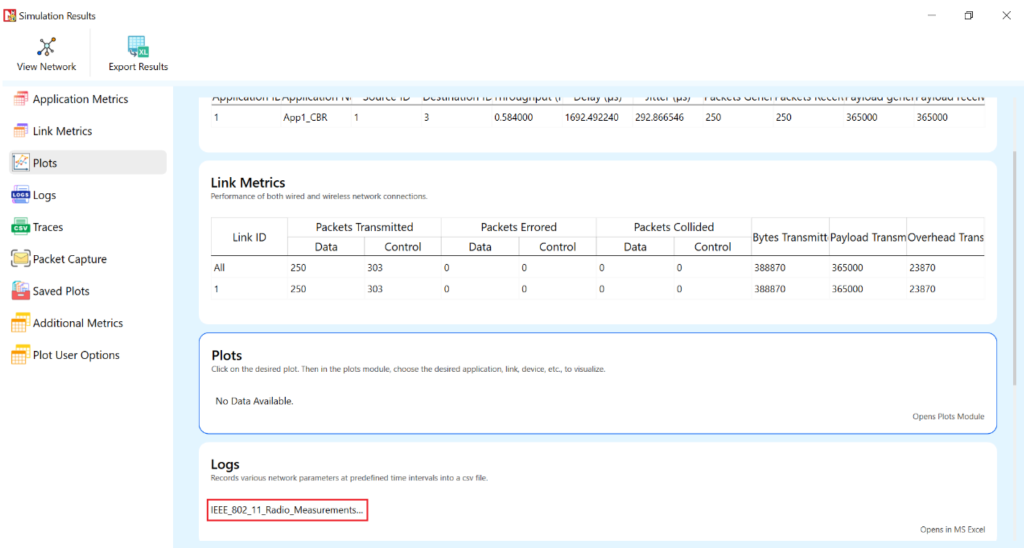


Figure 3-16: *Opening IEEE 802.11 Radio Measurements log from simulation results window*

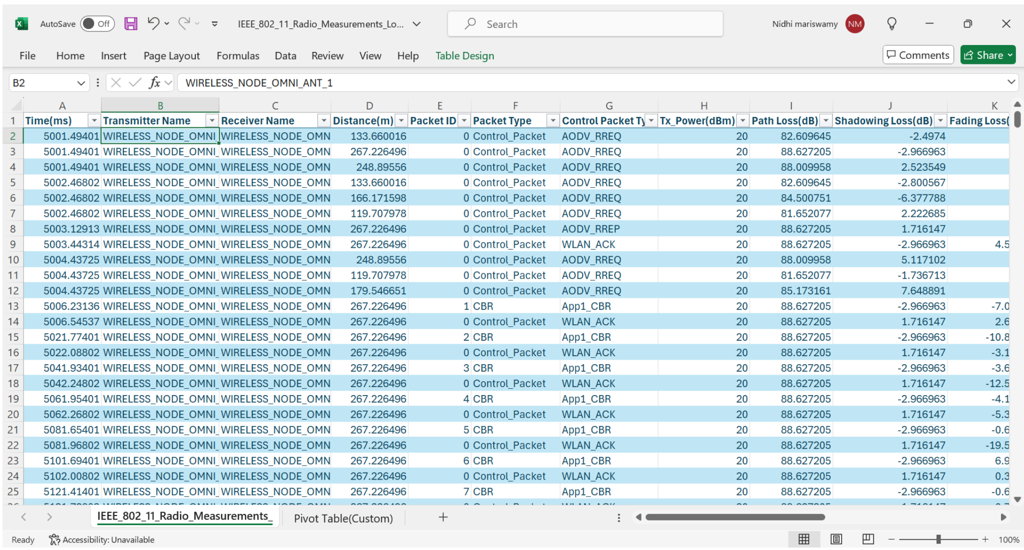


Figure 3-17: *IEEE 802.11 Radio Measurements log file*

NetSim plots

NetSim also provides energy and Wi-Fi radio measurement plots for MANET. Enabling the plots is explained in the section 2.6. Here is the plot showing the transmit energy vs. time for an AODV scenario with five nodes.

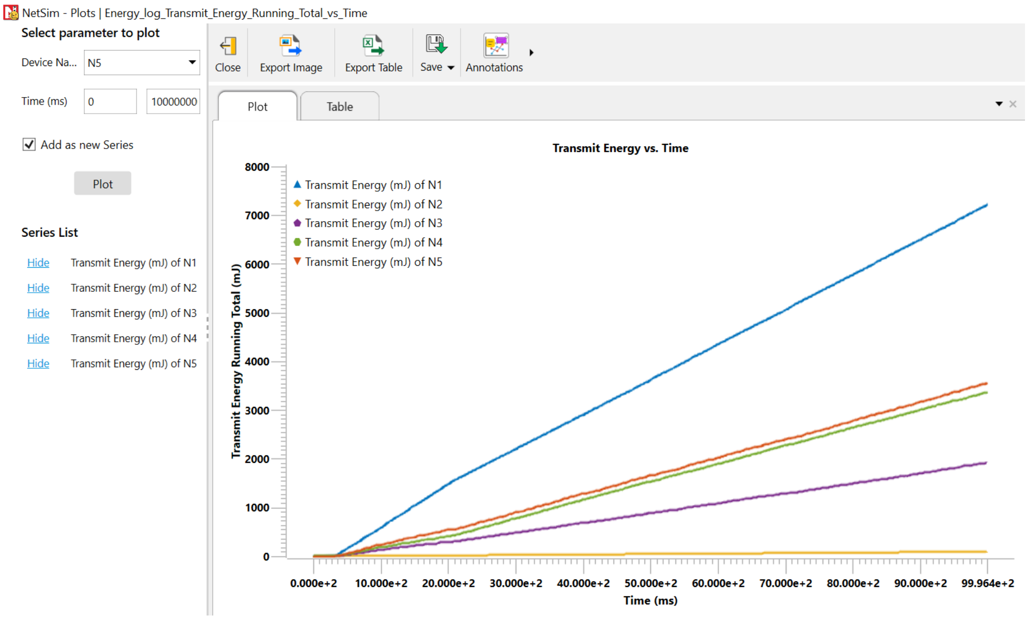


Figure 3-18: *Plot of Transmit Energy vs Time for MANET*

The Wi-Fi Radio measurement plots are shown in featured example in section 4.8.

4 Featured Examples

Sample configuration files for all networks are available in Examples Menu in NetSim Home Screen. These files provide examples on how NetSim can be used – the parameters that can be changed and the typical effect it has on performance.

4.1 AODV Routing

The Ad hoc On Demand Distance Vector Routing (AODV) protocol defines 3 message types:

- Route Requests (RREQs): RREQ messages are used to initiate the route-finding process.
- Route Replies (RREPs): RREP messages are used to finalize the routes.
- Route Errors (RERRs): RERR messages are used to notify the network of a link breakage in an active route.

The route discovery process involves ROUTE REQUEST (RREQ) and ROUTE REPLY (RREP) packets. The source node initiates the route discovery process using RREQ packets. The generated route request is forwarded to the neighbors of the source node and this process is repeated till it reaches the destination. On receiving an RREQ packet, an intermediate node with route to destination or the destination node generates an RREP containing the number of hops required to reach the destination. All intermediate nodes that participate in relaying this reply to the source node create a forward route to destination.

RERR message processing is initiated when Node detects a link break for the next hop of an active route or receives a data packet destined for a node for which it has no (active) route.

Open NetSim and Select Examples→Mobile Ad hoc Networks→MANET AODV then click on the tile in the middle panel to load the example as shown in below screenshot Figure 4-1.

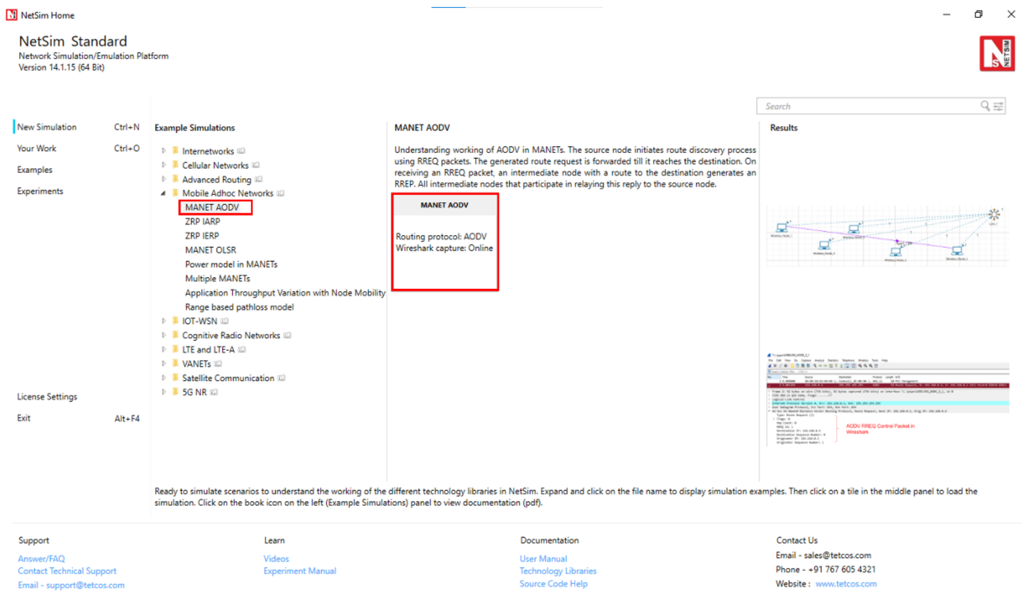


Figure 4-1: *List of scenarios for the example of MANET AODV*

The following network diagram illustrates, what the NetSim UI displays when you open the example configuration file see Figure 4-2.

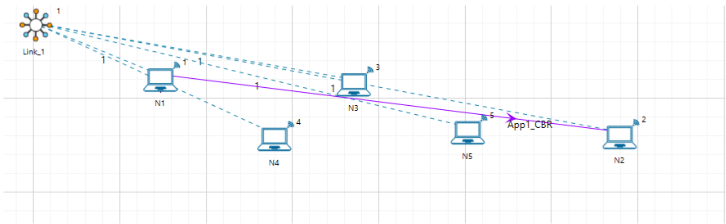
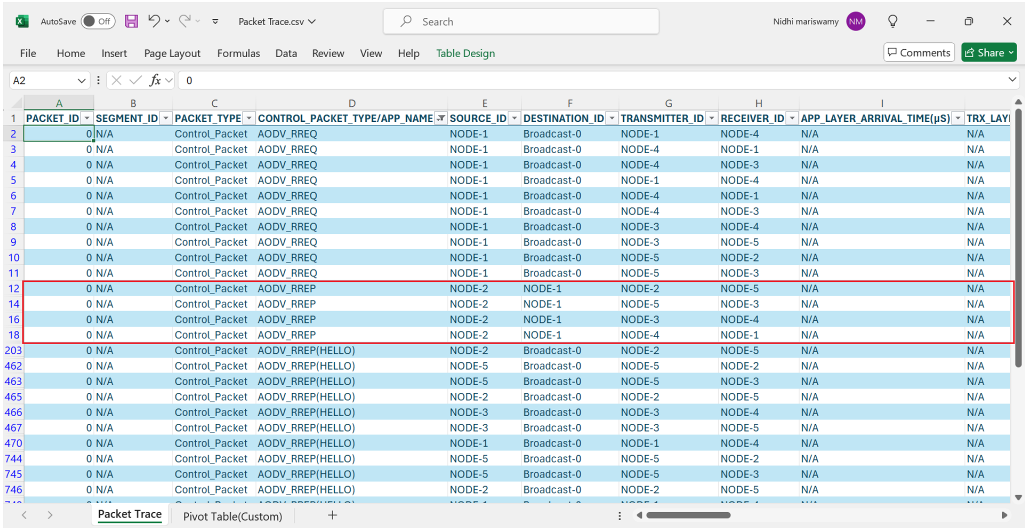


Figure 4-2: *Network set up for studying the MANET AODV*

4.1.1 Network Settings

- A network scenario is designed in NetSim GUI, consisting of 5 wireless nodes omni ants, named N1, N2, N3, N4, and N5, and one link in the “Standard MANET” of the “Mobile Ad hoc Network” library.
- In the general properties of N3, Wireshark Capture is set to Online. To configure any properties in the nodes, click on the node, expand the property panel on the right side, and change the properties as mentioned in the steps.
- In the position properties, set the mobility model as No-Mobility for all devices present in the GUI.
- The Medium Access Protocol is set to DCF in Interface 1(Wireless)→ Datalink layer of all the devices.
- Click on link and expand property panel on the right, and set the Channel Characteristics: Path loss only; Path loss model: Log Distance; Path loss exponent: 3.1.
- The routing protocol in the network layer is set to AODV for all nodes. As this is a global property, changing it on one node will affect all nodes.
- Packet trace is enabled by clicking on the configure report tab, allowing us to track the route that the packets have taken to reach the destination based on AODV.
- Configure the CBR application between two nodes by clicking on the set traffic tab from the ribbon at the top, selecting N1 as the source and N2 as the destination. Click on the created application and set the transport protocol to UDP, keeping the other properties as default.

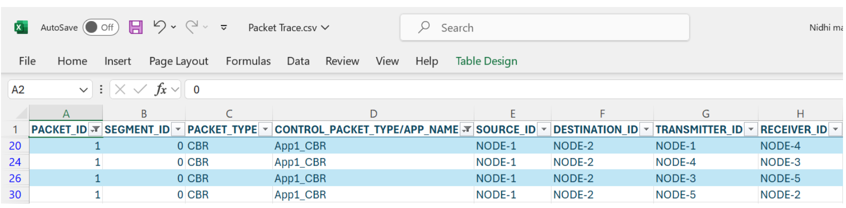
- Run simulation for 10 seconds.
- Open packet trace from simulation results window.
- The packet flow can be observed by filtering Control Packet Type/App Name to AODV RREQ, AODV RREP and AODV RREP (Hello) as shown below.



	PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/APP_NAME	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID	APP_LAYER_ARRIVAL_TIME(µS)	TRX_LAYI
2	0	N/A	Control_Packet	AODV_RREQ	NODE-1	Broadcast-0	NODE-1	NODE-4	N/A	N/A
3	0	N/A	Control_Packet	AODV_RREQ	NODE-1	Broadcast-0	NODE-4	NODE-1	N/A	N/A
4	0	N/A	Control_Packet	AODV_RREQ	NODE-1	Broadcast-0	NODE-4	NODE-3	N/A	N/A
5	0	N/A	Control_Packet	AODV_RREQ	NODE-1	Broadcast-0	NODE-1	NODE-4	N/A	N/A
6	0	N/A	Control_Packet	AODV_RREQ	NODE-1	Broadcast-0	NODE-4	NODE-1	N/A	N/A
7	0	N/A	Control_Packet	AODV_RREQ	NODE-1	Broadcast-0	NODE-4	NODE-3	N/A	N/A
8	0	N/A	Control_Packet	AODV_RREQ	NODE-1	Broadcast-0	NODE-3	NODE-4	N/A	N/A
9	0	N/A	Control_Packet	AODV_RREQ	NODE-1	Broadcast-0	NODE-3	NODE-5	N/A	N/A
10	0	N/A	Control_Packet	AODV_RREQ	NODE-1	Broadcast-0	NODE-5	NODE-2	N/A	N/A
11	0	N/A	Control_Packet	AODV_RREQ	NODE-1	Broadcast-0	NODE-5	NODE-3	N/A	N/A
12	0	N/A	Control_Packet	AODV_RREP	NODE-2	NODE-1	NODE-2	NODE-5	N/A	N/A
14	0	N/A	Control_Packet	AODV_RREP	NODE-2	NODE-1	NODE-5	NODE-3	N/A	N/A
16	0	N/A	Control_Packet	AODV_RREP	NODE-2	NODE-1	NODE-3	NODE-4	N/A	N/A
18	0	N/A	Control_Packet	AODV_RREP	NODE-2	NODE-1	NODE-4	NODE-1	N/A	N/A
203	0	N/A	Control_Packet	AODV_RREP(HELLO)	NODE-2	Broadcast-0	NODE-2	NODE-5	N/A	N/A
462	0	N/A	Control_Packet	AODV_RREP(HELLO)	NODE-5	Broadcast-0	NODE-5	NODE-2	N/A	N/A
463	0	N/A	Control_Packet	AODV_RREP(HELLO)	NODE-5	Broadcast-0	NODE-5	NODE-3	N/A	N/A
465	0	N/A	Control_Packet	AODV_RREP(HELLO)	NODE-2	Broadcast-0	NODE-2	NODE-5	N/A	N/A
466	0	N/A	Control_Packet	AODV_RREP(HELLO)	NODE-3	Broadcast-0	NODE-3	NODE-4	N/A	N/A
467	0	N/A	Control_Packet	AODV_RREP(HELLO)	NODE-3	Broadcast-0	NODE-3	NODE-5	N/A	N/A
470	0	N/A	Control_Packet	AODV_RREP(HELLO)	NODE-1	Broadcast-0	NODE-1	NODE-4	N/A	N/A
744	0	N/A	Control_Packet	AODV_RREP(HELLO)	NODE-5	Broadcast-0	NODE-5	NODE-2	N/A	N/A
745	0	N/A	Control_Packet	AODV_RREP(HELLO)	NODE-5	Broadcast-0	NODE-5	NODE-3	N/A	N/A
746	0	N/A	Control_Packet	AODV_RREP(HELLO)	NODE-2	Broadcast-0	NODE-2	NODE-5	N/A	N/A

Figure 4-3: *AODV different control packet in Packet trace*

- Source Node 1 initiates route discovery process using RREQ packets. The generated route request is broadcast to the neighbors of the source node i.e. Node 4.
- Node 4 broadcasts the RREQ packet to its neighboring nodes i.e., Node 3, Node 1 since Node 4 does not have a route to destination Node 2.
- Similarly, Node3 broadcasts the RREQ packet to Node 5 and Node 4.
- Node 5 broadcasts to Node 2 and Node 3.
- On receiving a RREQ packet, the Destination Node 2 generates a RREP packet and transmits to Node 5, Node 2 → Node 5, Node 5 → Node 3, Node 3 → Node 4, and Node 4 → Node 1.
- After receiving the RREP, the Source Node 1 starts sending Data packets to Node 2 (Node 1 → Node 4 → Node 3 → Node 5 → Node 2). To observe the same, filter the CONTROL PACKET TYPE/APP NAME to APP1_CBR and PACKET ID to 1 in packet trace.



	PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/APP_NAME	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID
20	1	0	CBR	App1_CBR	NODE-1	NODE-2	NODE-1	NODE-4
24	1	0	CBR	App1_CBR	NODE-1	NODE-2	NODE-4	NODE-3
26	1	0	CBR	App1_CBR	NODE-1	NODE-2	NODE-3	NODE-5
30	1	0	CBR	App1_CBR	NODE-1	NODE-2	NODE-5	NODE-2

Figure 4-4: *Data packet flow from source to destination*

In Wireshark, filter AODV packets and select the RREQ packets and expand Ad hoc on-demand distance vector protocol to view the above-mentioned fields of RREQ as shown in Figure 4-4.

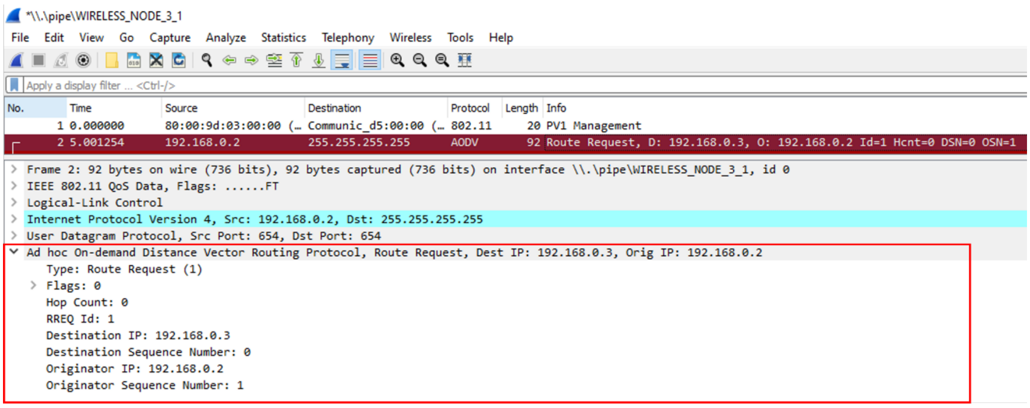


Figure 4-5: *AODV RREQ control packet in Wireshark*

Open Wireshark, filter AODV packets and select the RREP packets and expand Ad hoc on-demand distance vector protocol to view the above-mentioned fields of RREP as shown in Figure 4-5.

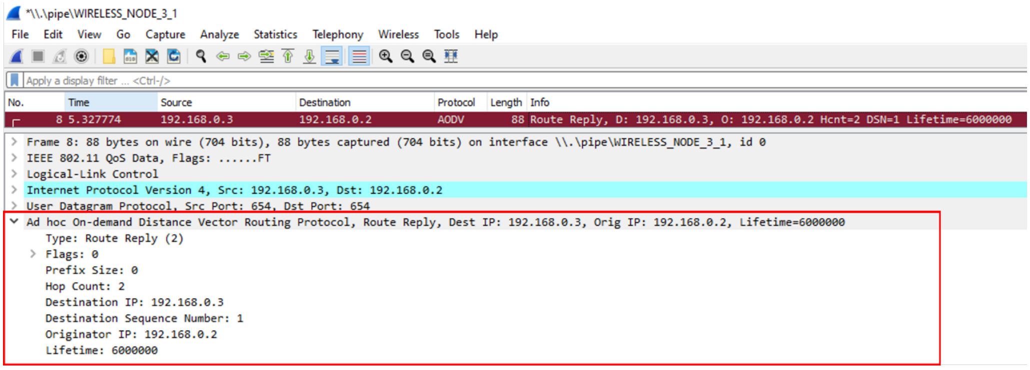


Figure 4-6: *AODV RREP control packet in Wireshark*

4.2 ZRP-IARP

Open NetSim and select Examples→Mobile Ad hoc Networks→ZRP IARP then click on the tile in the middle panel to load the example as shown in below screenshot Figure 4-6.

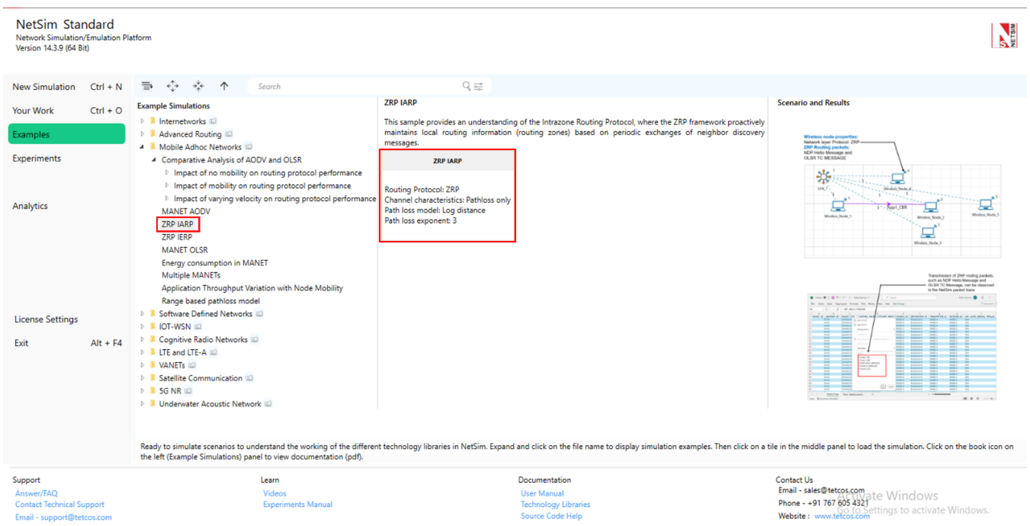


Figure 4-7: *List of scenarios for the example of ZRP-IARP*

The following network diagram illustrates what the NetSim UI displays when you open the example configuration file see Figure 4-7.

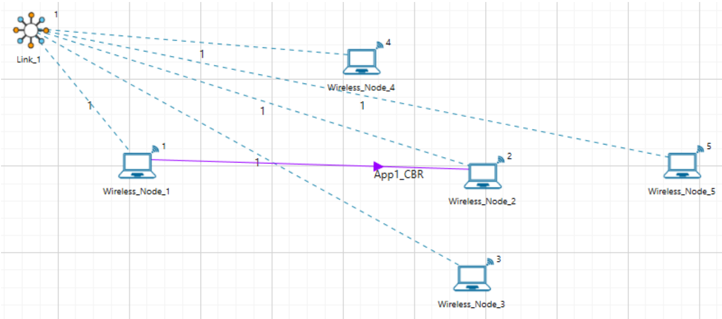


Figure 4-8: *Network set up for studying the ZRP-IARP*

4.2.1 Network Settings

1. Set grid length as 600m×300m from grid setting property panel on the right. This needs to be done before any device is placed on the grid.
2. A network scenario is designed in NetSim GUI consisting of 5 wireless nodes and one ad-hoc link in the "Standard MANET" module of MANET Network library.
3. To configure any properties in the nodes, click on the node, expand the property panel on the right side, and change the properties as mentioned in the below steps.
4. In the position properties set mobility model as no mobility for all devices present in GUI.
5. The Medium access protocol was set to DCF in Interface 1(wireless)→ Datalink layer of all Wireless nodes.
6. The routing protocol in the network layer is set to ZRP for all nodes. As this is a global property, changing it on one node will affect all nodes.
7. Click on link and expand property panel on the right and set the channel characteristics: path loss only, path loss model: log distance, path loss exponent: 3 under medium property.
8. Configure CBR application from set traffic tab in ribbon on the top between wireless node 1 to wireless node 2, click on the created application, expand the property panel on the right and set transport protocol to UDP.
9. Enable packet trace from configure reports tab in ribbon on the top.
10. Run simulation for 10 seconds.

4.2.2 Output

Open Packet trace from simulation results window and observe Control Packet Type/App Name.

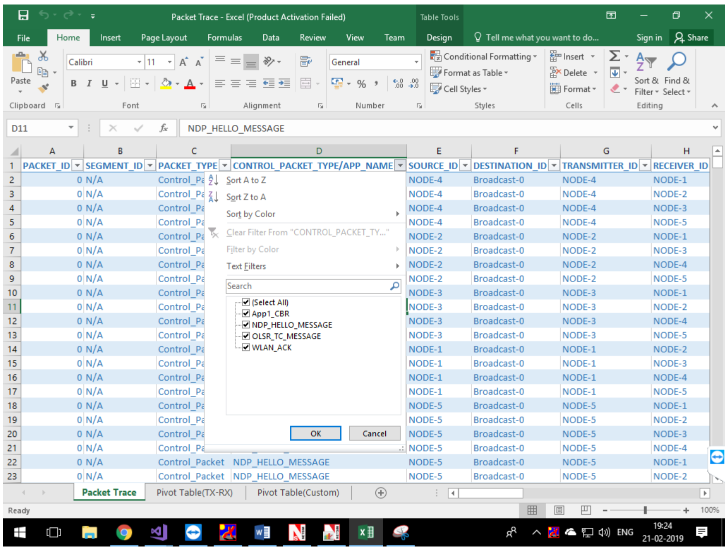


Figure 4-9: *Packet Trace*

Users can see only NDP Hello Message and OLSR TC MESSAGE since the destination node is within the zone. The ZRP framework proactively maintains local routing information (routing zones) based on periodic exchanges of neighbor discovery messages.

4.3 ZRP-IERP

Open NetSim and Select Examples → Mobile Ad hoc Networks → ZRP IERP then click on the tile in the middle panel to load the example as shown in below screenshot Figure 4-9.

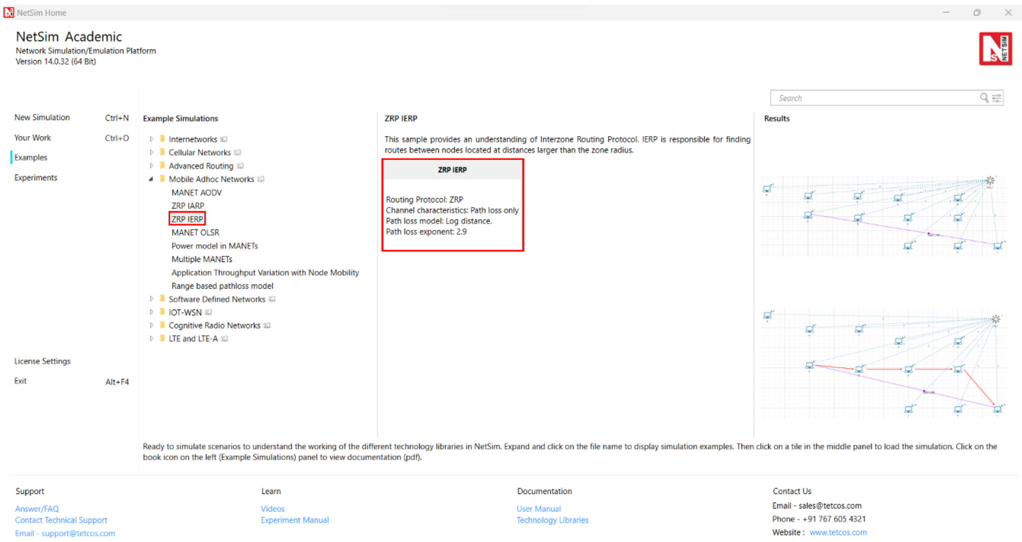


Figure 4-10: *List of scenarios for the example of ZRP-IERP*

The following network diagram illustrates what the NetSim UI displays when you open the example configuration file see Figure 4-10.

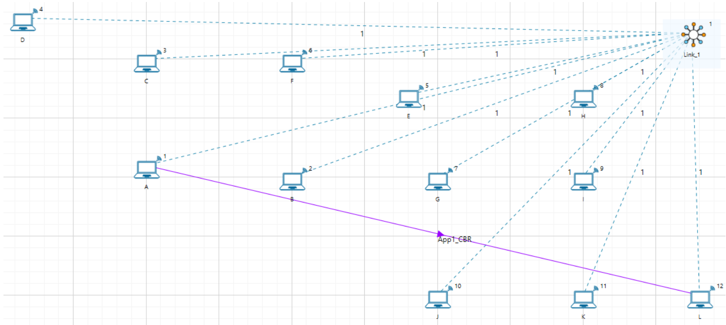


Figure 4-11: *Network set up for studying the ZRP-IERP*

4.3.1 Network Settings

1. Set grid length as 600m×300m from grid setting property panel on the right. This needs to be done before any device is placed on the grid.
2. A network scenario is designed in NetSim GUI consisting of 12 wireless nodes and one ad-hoc link in the "Standard MANET" of MANET Network library.
3. To configure any properties in the nodes, click on the node, expand the property panel on the right side, and change the properties as mentioned in the below steps.
4. In the position properties set mobility model as No mobility for all devices present in GUI.
5. The medium access protocol was set to DCF in Interface 1(wireless)→ Datalink layer of all wireless nodes.
6. The routing protocol in the network layer is set to ZRP for all nodes. As this is a global property, changing it on one node will affect all nodes.
7. Click on link and open property panel on the right and set the Channel characteristics: Log distance, Path loss exponent: 2.9.
8. Configure CBR application from wireless nodes 1 to wireless nodes 12 by clicking on set traffic tab in ribbon on the top. Click on the created application and set the transport protocol to UDP, keeping the other properties as default.
9. Enable Packet Trace from configure reports tab in the ribbon on the top.
10. Run simulation for 10 seconds.

4.3.2 Output

Open packet trace and filter Control Packet Type/App Name to IERP route request. In the below packet trace, node-1 is sending IERP route request packets to its peripheral nodes 2 and 3 since the destination is not present in node1's zone. Similarly, Node 2 transmits IERP route request packets to node 5 and 7 and node 3 transmits to node 4. To observe the IERP route request flow from the respective nodes filter the Transmitter Id to Node 1, Node 2 and Node 3 alone.

PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/APP_NAME	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-1	NODE-5	NODE-1	NODE-2
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-1	NODE-7	NODE-1	NODE-2
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-1	NODE-4	NODE-1	NODE-3
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-1	NODE-4	NODE-3	NODE-4
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-4	NODE-6	NODE-4	NODE-3
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-1	NODE-5	NODE-2	NODE-5
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-4	NODE-6	NODE-4	NODE-3
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-1	NODE-7	NODE-2	NODE-7
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-5	NODE-3	NODE-5	NODE-6
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-5	NODE-3	NODE-5	NODE-6
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-4	NODE-6	NODE-4	NODE-3
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-4	NODE-6	NODE-4	NODE-3
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-5	NODE-3	NODE-5	NODE-6
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-5	NODE-3	NODE-5	NODE-6
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-4	NODE-6	NODE-4	NODE-3
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-5	NODE-3	NODE-5	NODE-6
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-4	NODE-6	NODE-4	NODE-3
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-5	NODE-3	NODE-5	NODE-6
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-4	NODE-6	NODE-4	NODE-3
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-5	NODE-3	NODE-5	NODE-6
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-5	NODE-9	NODE-5	NODE-7
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-5	NODE-9	NODE-5	NODE-7
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-5	NODE-9	NODE-5	NODE-7
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-5	NODE-9	NODE-5	NODE-7
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-5	NODE-9	NODE-5	NODE-7
0	N/A	Control_Packet	IERP_ROUTE_REQUEST	NODE-5	NODE-9	NODE-5	NODE-7

Figure 4-12: *Packet Trace*

Node 7 generates an IERP Route Reply packet in response to the IERP Route Request since the destination node, Node 12, is present in the Node 7 zone. IERP Route Reply packet routes through Node 7 → Node 2 and Node 2 → Node 1. And the data packet routes through Node 1 → Node 2, Node 2 → Node 7, Node 7 → Node 9 and Node 9 → Node 12.

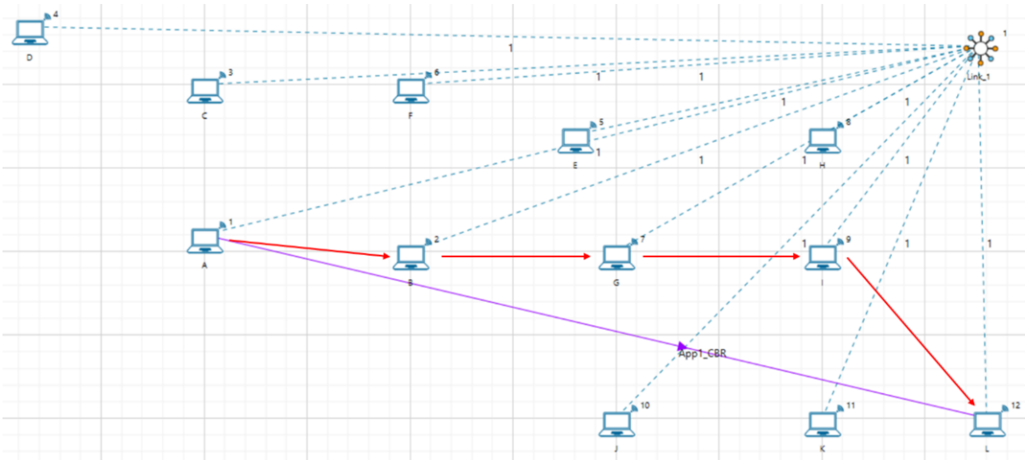


Figure 4-13: *Packets take the route 1 → 2 → 7 → 9 → 12 when running ZRP-IERP*

4.4 MANET-OLSR

4.4.1 Part-1: MPR Table Formation in NetSim

Introduction

In OLSR, only a subset of preselected nodes called MPR (Multi-Point Relays) are used to perform topological advertisements. Control messages (containing e.g. routing information) are broadcast and forwarded only by MPRs. This leads to a reduction in the number of transmitter nodes, in the overhead and in useless receptions of messages on nodes. The well-known storm problem due to broadcasting is avoided.

Creation of MPRs in OLSR

Neighbor Discovery

- Each node in the OLSR network periodically broadcasts HELLO messages to its immediate neighbors. These messages contain information about the node itself and its direct neighbors (1-hop neighbors).

- From these HELLO messages, a node learns about its 1-hop and 2-hop neighbors (the neighbors of its neighbors).

MPR Selection

Goal: The primary goal of selecting MPRs is to ensure that all 2-hop neighbors of a node can be reached through at least one of its MPRs.

A node selects a subset of its 1-hop neighbors as MPRs in such a way that these MPRs can cover all of its 2-hop neighbors. This means that every 2-hop neighbor must be reachable via at least one selected MPR.

The selection of MPRs is done based on degree of connectivity – nodes with a larger number of 2-hop neighbors might be preferred to cover more ground with fewer MPRs.

Route Calculation Using MPRs

Only the nodes selected as MPRs are responsible for forwarding control messages like Topology Control (TC) messages. This significantly reduces the number of transmissions, leading to less network overhead.

When a node needs to broadcast a TC message, it only forwards it to its MPRs, which in turn continue the broadcast, ensuring that the entire network receives the update.

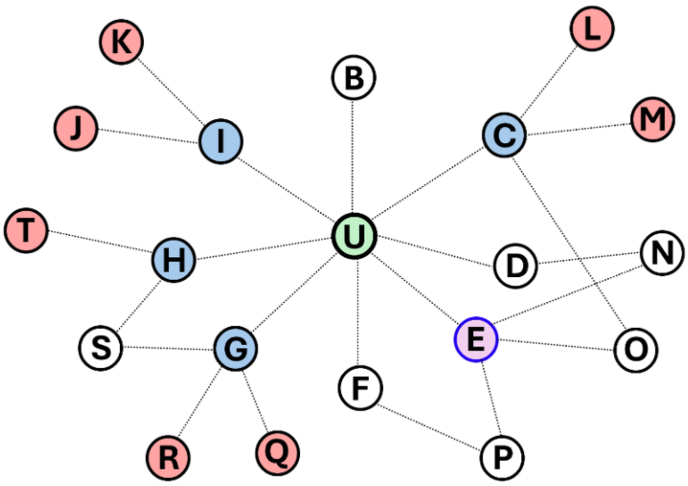


Figure 4-14: *Illustration of MPR Selection Algorithm. U is the node for which the MPR set is being calculated. Red nodes are the set of isolated nodes. Blue nodes are the set of MPR nodes obtained in the first step. Node E, in purple, is the MPR node selected in the second step. At the end of step 2, the remaining white nodes can be reached either directly or through one of the MPRs.*

In the first step, a node, node U (the green node in the diagram), selects relays from its one-hop neighbors (N1). These relays, referred to as MPR1 nodes (highlighted in blue), ensure that all isolated nodes in its two-hop neighborhood (N2), shown in red, are reachable. For instance, node T is considered an isolated node that can only connect to node U through node H. Therefore, node H is elected as an MPR in this step, ensuring node T can reach U in two hops.

In the second step, node U focuses on covering any remaining nodes in its two-hop neighborhood that were not connected by the initial MPR selection. It considers nodes in N2 that remain uncovered, as well as one-hop neighbors not chosen in the first step, like nodes B, F, E, and D. Node U then selects additional MPRs based on their connectivity to maximize coverage. For example, node E is chosen because it can cover multiple nodes in N2 that would otherwise remain isolated. The algorithm concludes when all nodes within two hops of node U are connected, forming an efficient routing set, represented as MPR(U) = {C, E, I, H, G} in the diagram. This process ensures optimal coverage while minimizing redundant transmissions.

3D Network Topology

In the network topology illustrated in Figure 4-13, connecting lines indicate that two nodes are within communication range of each other, while the absence of a line signifies that the nodes are out of range. The specific distance requirements between nodes create a set of spatial constraints that cannot be satisfied when nodes are arranged only in the X-Y plane. To resolve this geometric limitation, the nodes are positioned in three-dimensional space, utilizing the Z-axis to achieve the required connectivity pattern. The coordinates of the nodes are given in the table below.

Table 4-1: *XYZ coordinates for the 20 nodes in this scenario*

Node ID	X	Y	Z
1 (U)	500.00	250.00	150
2	500.00	150.00	230
3	571.00	179.00	70
4	600.00	250.00	230
5	571.00	321.00	70
6	500.00	350.00	230
7	429.00	321.00	70
8	399.83	249.15	230
9	429.00	179.00	70
10	394.06	105.73	0
11	382.76	113.09	130
12	571.78	97.90	130
13	614.60	118.89	0
14	624.00	289.00	160
15	564.00	263.00	0
16	545.27	396.84	170
17	455.00	437.00	65
18	393.35	300.00	0
19	352.03	339.62	150
20	330.36	252.03	300

A 3D view of the topology is shown in Figure 4-14 below.

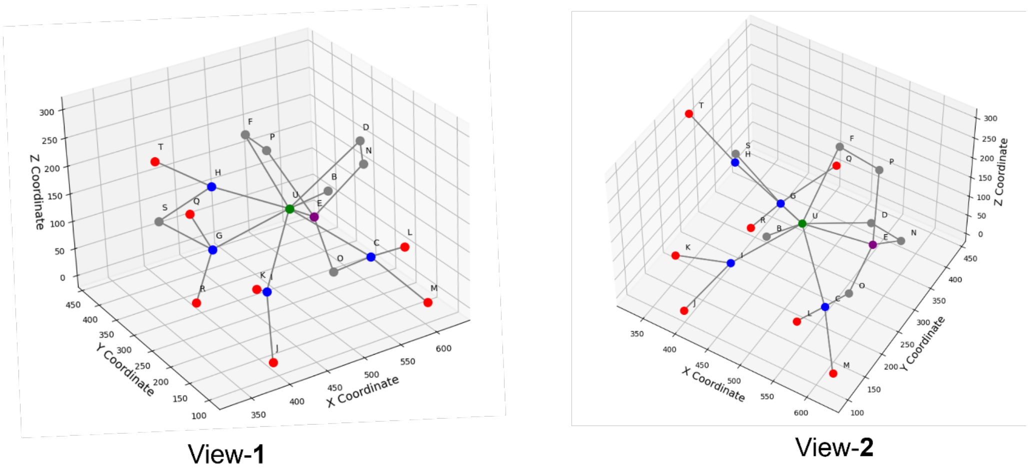


Figure 4-15: *3-D views of the topology. The range of the nodes is 130m. View-1 shows the network topology from a front right perspective, while View-2 provides a top down perspective.*

Network Setup

Open NetSim and Select Examples ▷ Mobile Ad hoc Networks ▷ MANET-OLSR then click on the tile in the middle panel to load the example as shown in below.

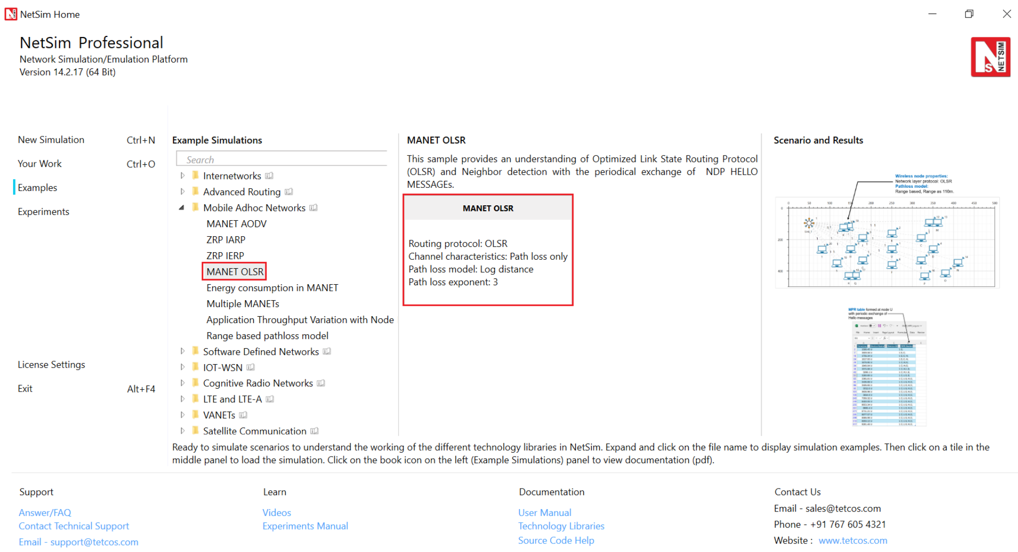


Figure 4-16: *List of scenarios for the example of MANET-OLSR*

The following steps were carried out to generate this scenario:

1. Set grid length as 1000 × 500 from grid setting property panel on the right. This needs to be done before any device is placed on the grid.
2. Create a scenario with 20 Nodes as shown in Figure 4-13.
3. Click on wireless node, expand the property panel on right and go to Position layer ▷ set Mobility model to No mobility in all nodes.
4. Set the Routing protocol to OLSR in Network layer of wireless nodes. As this is a global property, changing it on one node will affect all nodes.
5. Click on the link, expand link property on right and set the channel characteristics to pathloss and pathloss model as Range based, with range as 130m.
6. Enable OLSR Neighbor and MPR log by clicking on configure reports tab and plots as shown below.

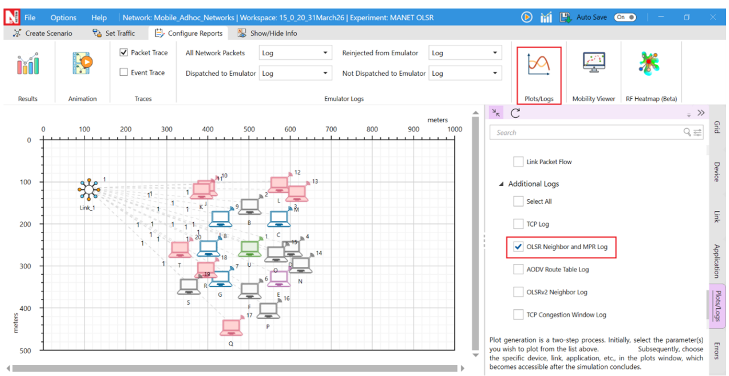
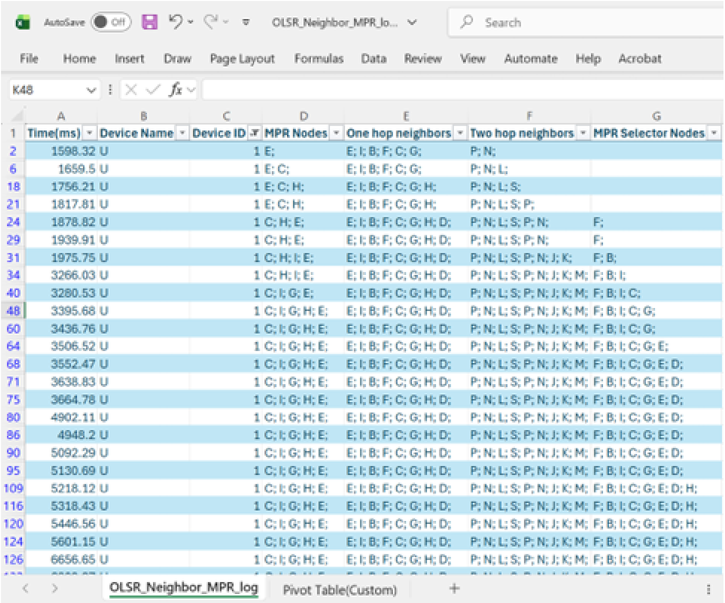


Figure 4-17: *Enabling OLSR Neighbor and MPR log*

7. Run the simulation for 50 seconds.

Results and Analysis

1. In the Results dashboard, click on logs tab and open OLSR_MPR_Log.csv file.
2. Filter the device name column to U.



	Time(ms)	Device Name	Device ID	MPR Nodes	One hop neighbors	Two hop neighbors	MPR Selector Nodes
2	1598.32	U	1	E;	E; I; B; F; C; G;	P; N;	
6	1659.5	U	1	E; C;	E; I; B; F; C; G;	P; N; L;	
18	1756.21	U	1	E; C; H;	E; I; B; F; C; G; H;	P; N; L; S;	
21	1817.81	U	1	E; C; H;	E; I; B; F; C; G; H;	P; N; L; S; P;	
24	1878.82	U	1	C; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N;	F;
29	1939.91	U	1	C; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N;	F;
31	1975.75	U	1	C; H; I; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K;	F; B;
34	3266.03	U	1	C; H; I; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M;	F; B; I;
40	3280.53	U	1	C; I; G; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M;	F; B; I; C;
48	3395.68	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M;	F; B; I; C; G;
60	3436.76	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M;	F; B; I; C; G;
64	3506.52	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M;	F; B; I; C; G; E;
68	3552.47	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M;	F; B; I; C; G; E; D;
71	3638.83	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M;	F; B; I; C; G; E; D;
75	3664.78	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M;	F; B; I; C; G; E; D;
80	4902.11	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M;	F; B; I; C; G; E; D;
86	4948.2	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M;	F; B; I; C; G; E; D;
90	5092.29	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M;	F; B; I; C; G; E; D;
95	5130.69	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M;	F; B; I; C; G; E; D;
109	5218.12	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M;	F; B; I; C; G; E; D; H;
116	5318.43	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M;	F; B; I; C; G; E; D; H;
120	5446.56	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M;	F; B; I; C; G; E; D; H;
124	5601.15	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M;	F; B; I; C; G; E; D; H;
126	6656.65	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M;	F; B; I; C; G; E; D; H;

Figure 4-18: *MPR table formed at node U*

- Initially, U starts with a single MPR node, "E," at 1598.32 ms. Over time, more nodes are added to the MPR list (e.g., "C", "H", "I", "G"), with some nodes being dropped or rearranged.
- We finally get the set of MPR nodes as "C; I; G; H; E".

4.4.2 Part-2: NDP and TC Messages in OLSR

Introduction

OLSR Hello Messages (NDP)

The OLSR Hello messages, part of the Neighbor Discovery Protocol (NDP), are exchanged between directly connected nodes. They enable each node to detect its one-hop and two-hop neighbors. These messages are used to establish and maintain neighbor relations, which are necessary for building an updated and accurate network topology. Hello messages include information about link status and the willingness of a node to participate in forwarding traffic for its neighbors. This process helps in selecting Multipoint Relays (MPRs), which minimize the number of transmissions required for routing updates.

OLSR TC Messages

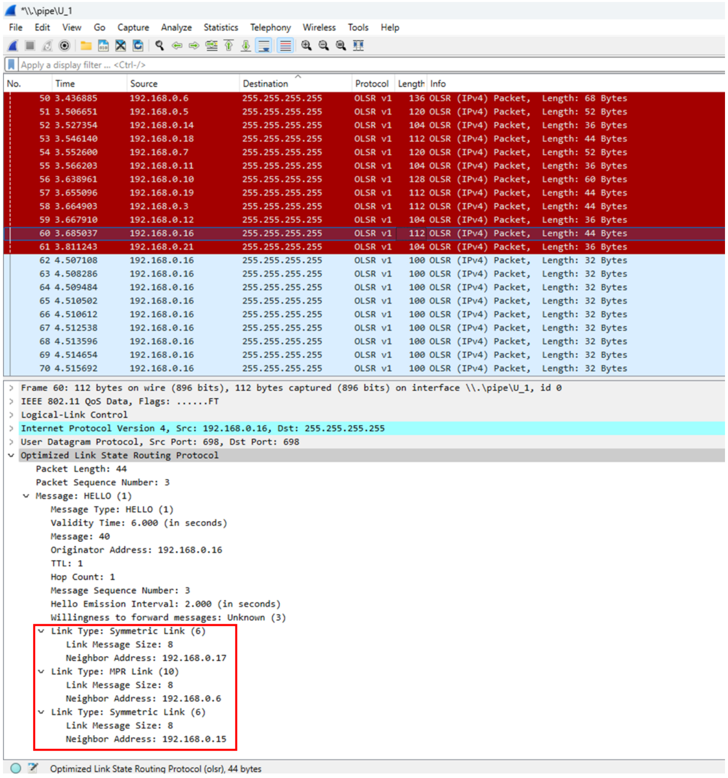


Figure 4-19: *OLSR Hello Message Broadcasting all Its Neighbors information with associated Link Type*

Network Setup

1. Consider the same scenario as Part -1.
2. Click on wireless node U, expand property panel on right and go to General Layer Set Wireshark Capture to Online.
3. Go to Configure Reports tab → Enable Packet trace.
4. Run the simulation for 50 seconds.

Results and Analysis

Wireshark is generated during the simulation of network.

The periodic exchange of Hello messages in OLSR dynamically updates the MPR (Multi-Point Relay) list of a device. You can observe this in the OLSR_MPR_Log.csv by filtering the Device Name column to "U."

Neighbor Discovery Process (NDP) or Hello Messages

See Figure 4-20.

Initial MPR Selection: At 1598.32 ms, the device starts with a single MPR node, "E." This means "E" was initially the best choice for relaying messages.

MPR List Evolution: Over time, more nodes like "C," "H," "I," and "G" are added to the list. This indicates the device is adapting to network changes, selecting new relays as network conditions evolve.

Dynamic Changes: Nodes are added or removed from the MPR list based on their current efficiency in relaying messages, reflecting ongoing adjustments to the network topology.

- Multiple MPR Nodes: We finally get the set of MPR nodes as "C; I; G; H; E".

Time(ms)	Device Name	Device ID	MPR Nodes	One hop neighbors	Two hop neighbors
1598.32	U	1	E;	E; I; B; F; C; G;	P; N;
1659.5	U	1	E; C;	E; I; B; F; C; G;	P; N; L;
1756.21	U	1	E; C; H;	E; I; B; F; C; G; H;	P; N; L; S;
1817.81	U	1	E; C; H;	E; I; B; F; C; G; H;	P; N; L; S; P;
1878.82	U	1	C; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N;
1939.91	U	1	C; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N;
1975.75	U	1	C; H; I; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K;
3266.03	U	1	C; H; I; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M; O;
3280.53	U	1	C; I; G; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M; O; Q; R; S;
3395.68	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M; O; Q; R; S; T;
3436.76	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M; O; Q; R; S; T; O;
3506.52	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M; O; Q; R; S; T; O;
3552.47	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M; O; Q; R; S; T; O;
3638.83	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M; O; Q; R; S; T; O;
3664.78	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M; O; Q; R; S; T; O;
4909.87	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M; O; Q; R; S; T; O;
5109.16	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M; O; Q; R; S; T; O;
5130.59	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M; O; Q; R; S; T; O;
5218.86	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M; O; Q; R; S; T; O;
5318.25	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M; O; Q; R; S; T; O;
5609.94	U	1	C; I; G; H; E;	E; I; B; F; C; G; H; D;	P; N; L; S; P; N; J; K; M; O; Q; R; S; T; O;

Figure 4-20: *MPR table formed at node U after periodic exchange of Hello messages.*

Topology Control (TC) Messages

TC (Topology Control) messages are periodically exchanged to inform nodes about the network's topology. Each node updates its routing table based on the information in these messages, which include details about MPRs (Multi-Point Relays) and their connections.

When a node receives a TC message, it uses the link information to add or adjust routes in its table, ensuring it always has the most efficient paths to other nodes. This dynamic updating keeps the network adaptive to changes, such as new routes or broken links.

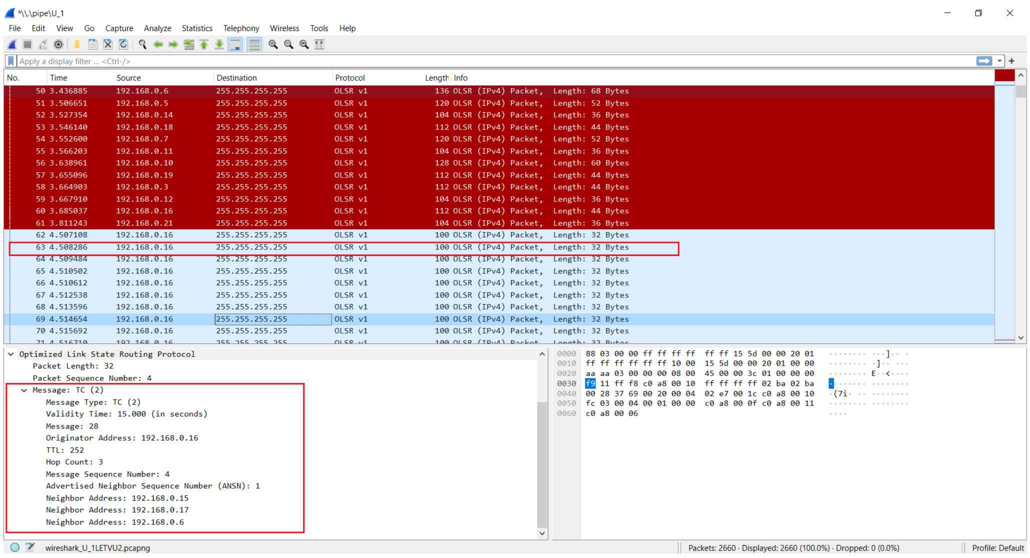


Figure 4-21: *TC Message Broadcasted from node to all its Neighbors, so that other nodes in the network can use this information to update their own routing tables.*

IP_Forwarding_Table

U

Network Destination	Netmask/Prefix len	Gateway	Interface	Metrics	Type
192.168.0.6	255.255.255.255	192.168.0.6	192.168.0.2	1	OLSR
192.168.0.10	255.255.255.255	192.168.0.10	192.168.0.2	1	OLSR
192.168.0.3	255.255.255.255	192.168.0.3	192.168.0.2	1	OLSR
192.168.0.7	255.255.255.255	192.168.0.7	192.168.0.2	1	OLSR
192.168.0.4	255.255.255.255	192.168.0.4	192.168.0.2	1	OLSR
192.168.0.8	255.255.255.255	192.168.0.8	192.168.0.2	1	OLSR
192.168.0.9	255.255.255.255	192.168.0.9	192.168.0.2	1	OLSR

Figure 4-22: *Routing Table of Node U*

The routing table shown in Figure 4-22 reflects these updates, displaying the optimal routes formed from the latest TC message exchanges.

How often are NDP Hello Messages and TC Messages exchanged in the Network?

Open Packet trace from simulation results window and filter Control Packet Type/App Name to NDP HELLO MESSAGE, Source ID to Node-1. All the nodes in the network exchange the NDP HELLO MESSAGEs periodically (for every 2 seconds—check NETWORK LAYER ARRIVAL TIME column) to detect the neighbors. In the below screenshot, Node-1 is broadcasting NDP HELLO MESSAGES to its neighbors 2, 3, 4, 5, 6, 7, 8 and 9 for every 2 seconds as shown below.

	A	B	C	D	E	F	G	H	K
1	PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/APP_NAME	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID	NW_LAYER_ARRIVAL_TIME(µS)
16	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-2	0
17	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-3	0
18	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-4	0
19	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-5	0
20	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-6	0
21	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-7	0
22	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-8	0
23	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-9	0
108	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-2	1719373
109	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-3	1719373
110	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-4	1719373
111	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-5	1719373
112	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-6	1719373
113	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-7	1719373
114	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-8	1719373
115	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-9	1719373
183	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-2	3422280
184	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-3	3422280
185	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-4	3422280
186	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-5	3422280
187	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-6	3422280
188	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-7	3422280
189	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-8	3422280
190	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-9	3422280
3367	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-2	5174458
3368	0	N/A	Control_Packet	NDP_HELLO_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-3	5174458

Figure 4-23: *NDP HELLO MESSAGES to its neighbors 2, 3, 4, 5, 6, 7, 8 and 9 for every 2 seconds in Packet Trace.*

You can observe in the packet trace that hello packets are exchanged every 1.7 seconds. This is obtained from

Actual Message Interval = Message Interval – Jitter

This is applicable for TC messages as well.

Now filter Control Packet Type/App Name to OLSR TC Message, Source Id and Transmitter Id to Node-1. All nodes in the network, broadcasts Topology control (TC) messages (for every 5 seconds—check Network layer arrival time column) in order to build the topology information base. In the below screenshot, node-1 is broadcasting OLSR TC Message to its neighbors 2, 3, 4, 5, 6, 7, 8 and 9 for every 5 seconds as shown below.

	A	B	C	D	E	F	G	H	K
1	PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/APP_NAM	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID	NW_LAYER_ARRIVAL_TIME(µs
748	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-2	4633567
749	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-3	4633567
750	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-4	4633567
751	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-5	4633567
752	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-6	4633567
753	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-7	4633567
754	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-8	4633567
755	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-9	4633567
1293	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-2	4758781.706
1294	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-3	4758781.706
1295	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-4	4758781.706
1296	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-5	4758781.706
1297	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-6	4758781.706
1298	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-7	4758781.706
1299	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-8	4758781.706
1300	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-9	4758781.706
3378	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-2	5197798.906
3379	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-3	5197798.906
3380	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-4	5197798.906
3381	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-5	5197798.906
3382	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-6	5197798.906
3383	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-7	5197798.906
3384	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-8	5197798.906
3385	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-9	5197798.906
4744	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-2	5709693.821
4745	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-3	5709693.821
4746	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-4	5709693.821
4747	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-5	5709693.821
4748	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-6	5709693.821
4749	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-7	5709693.821
4750	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-8	5709693.821
4751	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-9	5709693.821
6657	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-2	6855039.178
6658	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-3	6855039.178
6659	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-4	6855039.178
6660	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-5	6855039.178
6661	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-6	6855039.178
6662	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-7	6855039.178
6663	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-8	6855039.178
6664	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-9	6855039.178
7511	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-2	9290618.706
7512	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-3	9290618.706
7513	0	N/A	Control_Packet	OLSR_TC_MESSAGE	NODE-1	Broadcast-0	NODE-1	NODE-4	9290618.706

Figure 4-24: *OLSR TC Message sent to neighbors 2, 3, 4, 5, 6, 7, 8 and 9, every 5 seconds as can be seen in packet trace*

4.5 Comparative analysis of AODV and OLSR in static and mobility scenarios

4.5.1 Introduction

Mobile Ad hoc Networks (MANETs) are self-organizing wireless networks that operate without a fixed infrastructure. The dynamic and distributed nature of MANETs introduces challenges for routing protocols, particularly in handling topology changes and maintaining efficiency under varying traffic loads. Routing protocols for MANETs are broadly categorized into reactive and proactive approaches, each with distinct mechanisms and trade-offs.

- Ad-hoc On-Demand Distance Vector (AODV): AODV is a reactive routing protocol that establishes routes only when needed. As described by Clausen et al., AODV initiates route discovery by broadcasting route request packets, followed by unicast replies for discovered routes. This approach reduces control overhead in static or low-traffic networks. However, frequent route rediscoveries caused by mobility or high traffic densities can increase overhead.
- Optimized Link State Routing (OLSR): OLSR is a proactive protocol that maintains routing tables for all nodes in the network at all times. Clausen et al. highlight OLSR's use of Multipoint Relays (MPRs) to optimize control traffic by reducing redundant retransmissions during periodic updates. While OLSR ensures immediate route availability, it generates constant control traffic regardless of traffic flow or mobility.

This example evaluates and compares the performance of AODV and OLSR under three scenarios:

- No mobility: Nodes remain stationary throughout the simulation.
- With mobility: Nodes follow a random walk mobility model, but with a fixed speed.
- Varying velocity: Nodes move at speeds ranging from 0 m/s to 100 m/s.

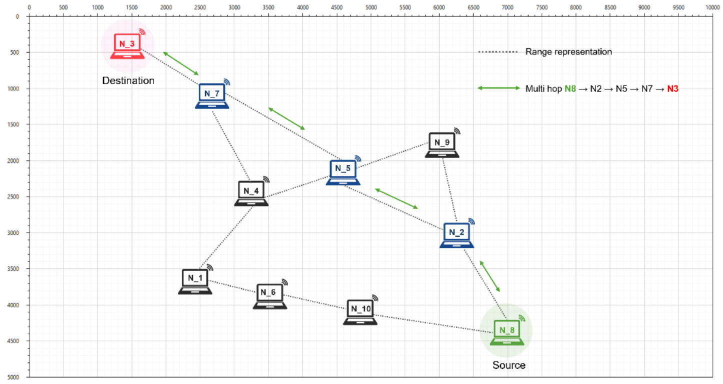


Figure 4-25: *10-Node Network Topology in MANET Simulation. The area of operation is set to* $10km \times 5km$*. Nodes communicate wirelessly using ad hoc routing protocols. The range of each node is set to* 1.7 *km and transmissions could be single hop or multi hop.*

We analyze which protocol is more resource-efficient under different network conditions, focusing on control traffic overhead, which refers to the additional network traffic generated by routing protocols during activities such as route discovery, updates, and maintenance. Since excessive control traffic can degrade performance in MANETs by consuming the already limited bandwidth, minimizing this overhead is crucial for efficient network operation. By comparing AODV and OLSR, this study provides insights into their suitability for specific scenarios, helping users make appropriate decisions based on trade-offs between scalability, bandwidth utilization, and control overhead.

4.5.2 Simulation Setup

4.5.3 Network Configuration

These settings have been pre-configured in the simulation environment.

Table 4-2: *Simulation parameters for MANET scenario*

Simulation Parameters	Value
Environment size	10000 × 5000
Mobility model	No mobility/Random walk
Velocity	10 m/s (only for Random walk)
Calculation Interval	2 second (only for Random walk)
Routing protocol	AODV/OLSR
MAC protocol	802.11 b
Transmission range	1700 m

1. Setting transmission range in NetSim: Click on the link connecting the nodes and open the link properties by navigating to the medium property in the link properties panel (RHS).
2. Set channel characteristics to pathloss, choose Range based for the pathloss model, and enter 1700 m in the Range (m) field.

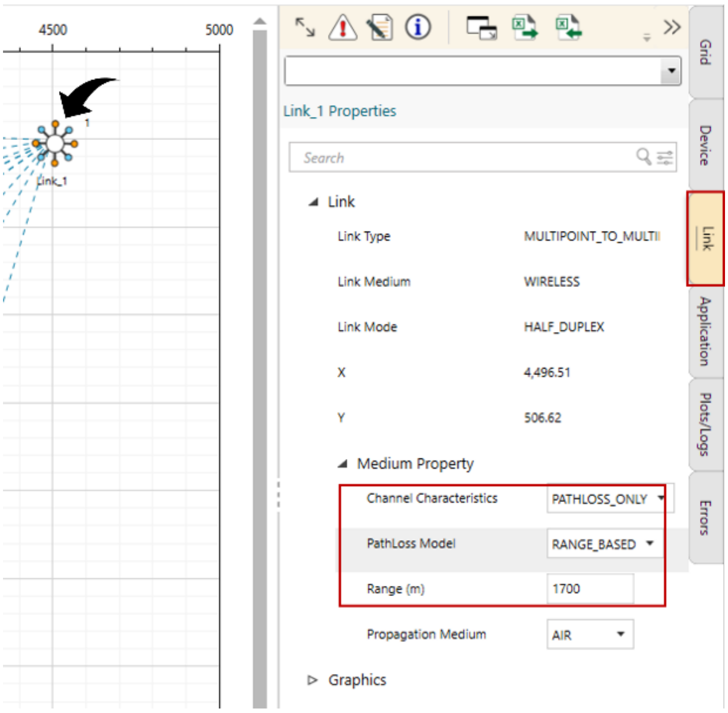


Figure 4-26: *Configuring transmission range in NetSim link properties.*

3. Enable packet trace from the configure reports tab in ribbon on top.
4. Run the simulation for 50 seconds.

4.5.4 Scenario Setup

For both AODV and OLSR, we simulate 30 cases with varying numbers of applications. Each case increases the number of applications by one, starting from a single application in Case 1 and going up to 30 applications in Case 30.

Repetition of Simulations

To reduce the impact of randomness, each scenario (AODV and OLSR) is repeated with three sets of simulations:

- Set 1: Initial set of source-destination pairs.
- Set 2: Second set of source-destination pairs.
- Set 3: Third set of source-destination pairs.

The final results are the averaged control traffic overhead across these three sets.

In the NetSim GUI, we provide configuration files for three cases: mobility, No-mobility, and velocity. The dataset includes:

- Mobility Cases:
  - Set 1: 30 cases of AODV and OLSR.
- No-Mobility Cases:
  - Set 1: 30 cases of AODV and OLSR.

Velocity Cases:

- Set 1: 10 cases of AODV and OLSR across varying velocities.
- The complete set of configuration files is available for download: GitHub Zip folder download link: `https://github.com/NetSim-TETCOS/Comparative-analysis-of-AODV-and-OLSR-v14.4/archive/refs/heads/main.zip`
- Click on the link above to download the comparative analysis examples.
- Extract the zip folder. The extracted project folder consists of case files for mobility, No-mobility, and velocity cases.
- Instructions for importing the workspace are provided in section 4.9.2 of the NetSim user manual.

4.5.5 Steps for Control Traffic Overhead Calculation

Running the Simulation

- Open NetSim and Select Examples→ Mobile Ad hoc Networks → Comparative Study of AODV and OLSR

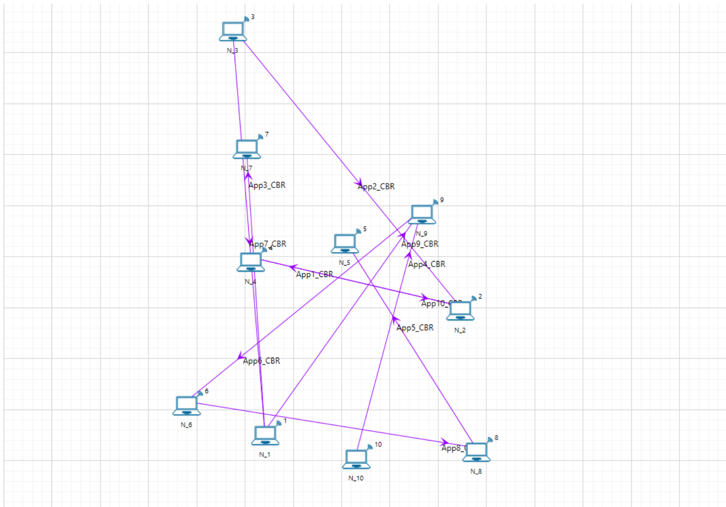


Figure 4-27: *Network Scenario. With 10 wireless nodes configured with 10 traffic flows with each other*

- For this example, Open the No-mobility case-10 scenario (e.g., No-mobility case ▷ Set-1 ▷ AODV ▷ case-10), which is configured with 10 applications.
- Run the simulation for 50 seconds.

Accessing the Packet Trace

- After each simulation is completed, open the packet trace file generated from the result dashboard.

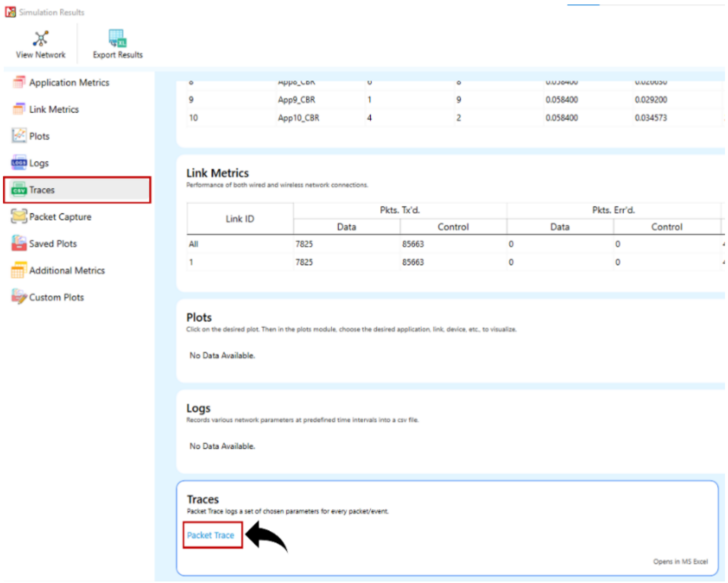


Figure 4-28: *Opening packet trace from simulation results window*

This file contains detailed logs for each packet transmitted in the network.

Filtering Control Packets for AODV

- In this step, we filter AODV control packets specifically to calculate the control traffic overhead accurately:

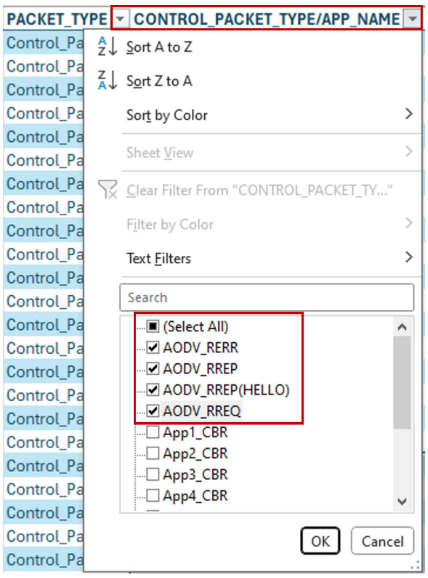


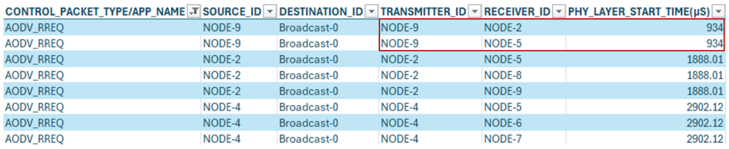
Figure 4-29: *Filtering AODV Control Packets in Packet Trace*

- Filtering by Control Packet Type: We select only rows where Control Packet Type/App Name specifies AODV. This isolates the AODV-specific control traffic data.

Removing Duplicate Entries

Broadcast control packets, used by AODV/OLSR during route discovery, are transmitted to all neighbouring nodes within range. In all these cases the same packet is received and logged by multiple nodes.

Since each neighbor logs the packet, the same packet(s) appears multiple times in the data, however the packet(s) was transmitted only once by the sender.



CONTROL_PACKET_TYPE/APP_NAME	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID	PHY_LAYER_START_TIME(µS)
AODV_RREQ	NODE-9	Broadcast-0	NODE-9	NODE-2	934
AODV_RREQ	NODE-9	Broadcast-0	NODE-9	NODE-5	934
AODV_RREQ	NODE-2	Broadcast-0	NODE-2	NODE-5	1888.01
AODV_RREQ	NODE-2	Broadcast-0	NODE-2	NODE-8	1888.01
AODV_RREQ	NODE-2	Broadcast-0	NODE-2	NODE-9	1888.01
AODV_RREQ	NODE-4	Broadcast-0	NODE-4	NODE-5	2902.12
AODV_RREQ	NODE-4	Broadcast-0	NODE-4	NODE-6	2902.12
AODV_RREQ	NODE-4	Broadcast-0	NODE-4	NODE-7	2902.12

Figure 4-30: *Observing the phy layer start time from packet trace*

- For example, a packet sent by Node-9 may be received by multiple nodes (Node-2, Node-5, etc.) at the same Phy layer start time(μS).
- By keeping only unique entries based on Packet Id and Phy layer start time(μS), we avoid counting the same packet multiple times, which would otherwise inflate the overhead.

- Steps to remove Duplicate packet entries.
- Go to Data ▷ Remove Duplicates in your spreadsheet software.
- In the Remove Duplicates dialog:

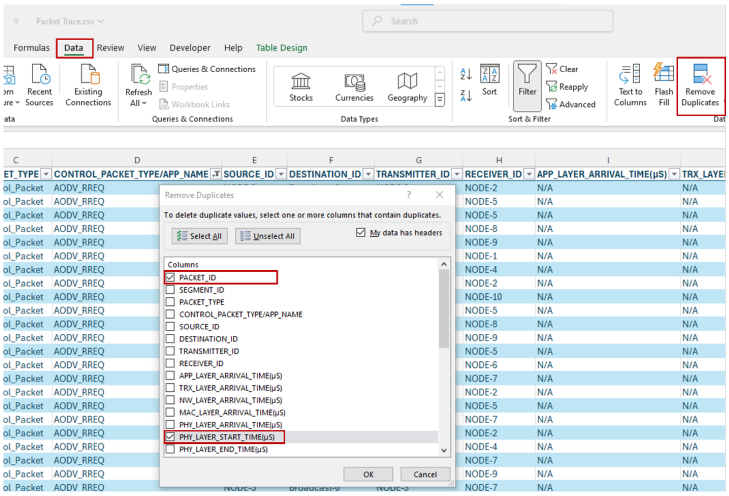


Figure 4-31: *Removing Duplicate AODV Control Packets Based on Packet ID and Start Time*

- Unselect all columns.
- Select only the columns Packet Id and Phy layer start time(μS).
- This will remove duplicate AODV control packets based on packet ID and start time.

Calculating the Control Traffic Overhead

In the filtered data, locate the Phy layer pay load(Bytes) column.

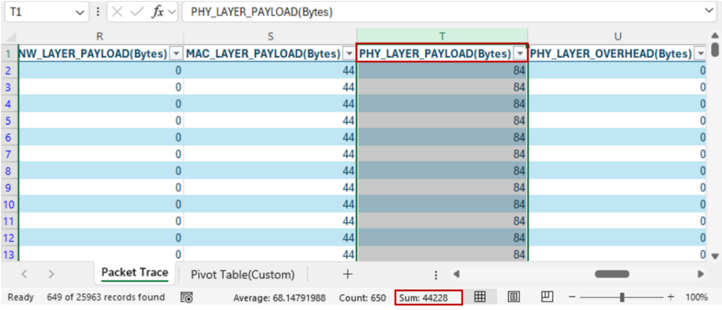


Figure 4-32: *Calculating the total control traffic overhead*

- Finally, we calculate the sum of Phy layer payload (Bytes) for the unique entries. This gives the actual control traffic overhead for AODV, ensuring an accurate representation of the protocol's overhead without duplicate broadcasts.

- Record this sum as the Control traffic overhead for the current case of AODV.

Repeating for OLSR

- Configure the network layer protocol to OLSR instead of AODV.
- Follow steps from 4.5.5.3 to 4.5.5.5 to calculate the control traffic overhead for each case of OLSR.
- In step 4.5.5.3, filter for OLSR packets in the Control Packet Type/App Name column.

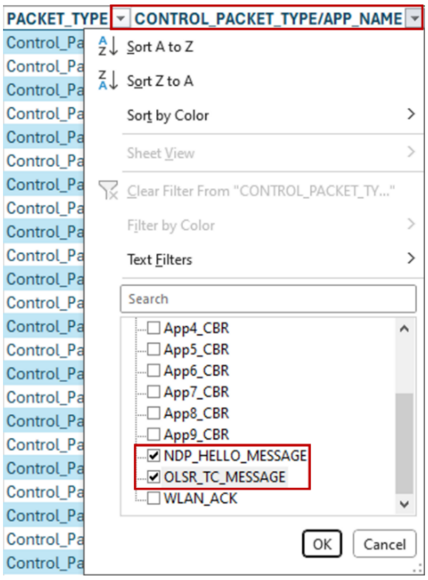


Figure 4-33: *Filtering OLSR Control Packets in Packet Trace*

- Here just filter NDP Hello Message and OLSR TC Message
- Repeat steps 4.5.5.1 to 4.5.5.5 for each case (Case 1 to Case 30) of AODV and OLSR.
- Record the overhead values.

Averaging Across Sets

- Calculate the control traffic overhead for Set 1.
- Repeat the calculations for Set 2 and Set 3.

- Average the control traffic overhead values from sets 1, 2, and 3 to obtain the final control traffic overhead for each case.
- We have used the same method to get the results for Mobility case also.

4.5.6 Results and Discussion

No-Mobility cases

The results for the No-mobility case of these three sets are as follows:

Table 4-3: *Control Traffic Overhead (Bytes) for OLSR and AODV across Three Simulation Sets (No-Mobility)*

	Set 1 (Ctrl Traffic OH)		Set 2 (Ctrl Traffic OH)		Set 3 (Ctrl Traffic OH)		Average	
No. of Traffic flows	AODV(B)	OLSR(B)	AODV(B)	OLSR(B)	AODV(B)	OLSR(B)	AODV(B)	OLSR(B)
1	25408	318344	26176	276420	25424	319832	25669	304865
2	26520	276716	26972	275840	28160	290088	27217	280881
3	27896	268724	26972	275644	30924	288556	28597	277641
4	27348	268388	27588	276344	30228	280944	28388	275225
5	28204	276944	29308	288980	32320	282740	29944	282888
6	31052	283036	30324	290512	32284	280896	31220	284815
7	30848	274488	32180	269492	29772	303224	30933	282401
8	32584	272836	32956	302984	31596	295732	32379	290517
9	34360	275576	33108	359952	35016	281708	34161	305745
10	33616	274608	36252	323924	32548	308024	34139	302185
11	36476	287084	90788	367112	34268	296432	53844	316876
12	38444	280592	44644	322924	38084	281432	40391	294983
13	38376	299092	38940	314984	39712	290436	39009	301504
14	49996	271380	48136	350124	35320	313092	44484	311532
15	48060	370212	48212	321040	42052	291232	46108	327495
16	46852	311964	59984	334160	42356	324404	49731	323509
17	51872	299616	91728	337736	38832	345300	60811	327551
18	51668	299444	91840	316672	57864	319764	67124	311960
19	52184	298344	69356	311544	47020	334884	56187	314924
20	52824	284920	75636	305984	78740	292116	69067	294340
21	75048	328816	78500	347088	542100	327960	231883	334621
22	79456	263516	455780	337488	59932	284844	198389	295283
23	89332	268588	2380728	339088	79424	311472	849828	306383
24	85116	289088	2915412	392956	126364	280832	1042297	320959
25	82756	263900	1369760	351040	1989620	339460	1147379	318133
26	2083272	320484	2360080	389672	1786548	317028	2076633	342395
27	1385988	298800	3691028	322368	2056808	351144	2377941	324104
28	2168944	334812	2564324	309036	3477228	302272	2736832	315373
29	1064636	330868	3782316	329388	3560280	272748	2802411	311001
30	2556544	356724	4280888	392928	2235200	309268	3024211	352973

This table presents the control overhead data for 30 traffic flows, averaged across three simulation sets (Set 1, Set 2, and Set 3) with unique source-destination pairs. The averaging process reduces randomness and ensures a more accurate comparison for both the no mobility and mobility scenarios.

Plot:

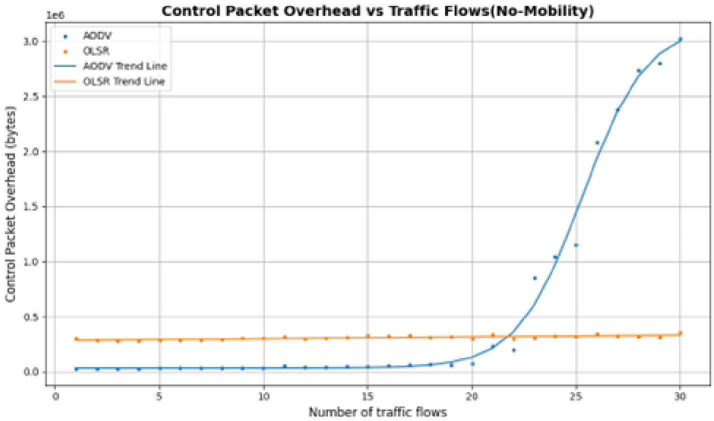


Figure 4-34: *Control Packet Overhead vs. Number of traffic flows in No-mobility case*

Mobility cases

The results for the Mobility case of these three sets are as follows:

Table 4-4: *Control Traffic Overhead (Bytes) for OLSR and AODV across Three Simulation Sets (Mobility)*

	Set 1 (Ctrl Traffic OH)		Set 2 (Ctrl Traffic OH)		Set 3 (Ctrl Traffic OH)		Average	
No. of flows	AODV(B)	OLSR(B)	AODV(B)	OLSR(B)	AODV(B)	OLSR(B)	AODV(B)	OLSR(B)
1	25468	412680	25468	412680	27564	352936	26167	392765
2	26100	314384	27732	490148	27568	384508	27133	396347
3	28284	297648	27816	470056	27684	419320	27928	395675
4	28608	383552	30364	304816	31836	478392	30269	388920
5	29212	414160	31396	316880	30684	372984	30431	368008
6	31328	443772	32928	456948	31876	434908	32044	445209
7	32536	350376	35684	465236	32808	493136	33676	436249
8	32752	370728	31396	373828	32808	433900	32319	392819
9	35044	322424	31636	350124	33824	398684	33501	357077
10	34068	373596	34280	401796	36032	308160	34793	361184
11	39036	376044	37544	349312	37248	343312	37943	356223
12	36660	354536	39668	458356	39644	394156	38657	402349
13	37036	315992	48180	369068	44104	416508	43107	367189
14	47028	443904	42636	449600	53084	395444	47583	429649
15	50748	408052	50012	341944	355392	354320	152051	368105
16	59056	420716	1355420	448332	60640	414000	491705	427683
17	62776	423056	183964	506256	62644	337688	103128	422333
18	60436	459968	71752	335768	52292	442308	61493	412681
19	126680	377748	60120	261748	77252	431580	88017	357025
20	63424	349852	110380	331340	72000	392752	81935	357981
21	98604	396896	2194176	363072	99292	359712	797357	373227
22	743344	483432	3502212	442140	76796	522720	1440784	482764
23	3766092	419096	2906148	487928	100112	366276	2257451	424433
24	511088	363200	3594464	491992	1515364	390620	1873639	415271
25	3115056	436116	2297716	389652	1916896	397768	2443223	407845
26	2756380	384908	2900080	429592	2454956	453184	2703805	422561
27	1902272	361012	4675832	471316	2272428	424092	2950177	418807
28	1716844	438220	4297136	442520	2845088	407636	2953023	429459
29	2546728	328956	3420656	319520	2909900	425556	2959095	358011

Table 4-4: *(continued)*

	Set 1 (Ctrl Traffic OH)		Set 2 (Ctrl Traffic OH)		Set 3 (Ctrl Traffic OH)		Average	
No. of flows	AODV(B)	OLSR(B)	AODV(B)	OLSR(B)	AODV(B)	OLSR(B)	AODV(B)	OLSR(B)
30	776816	417396	3729096	372632	3061636	399436	2522516	396488

Plot:

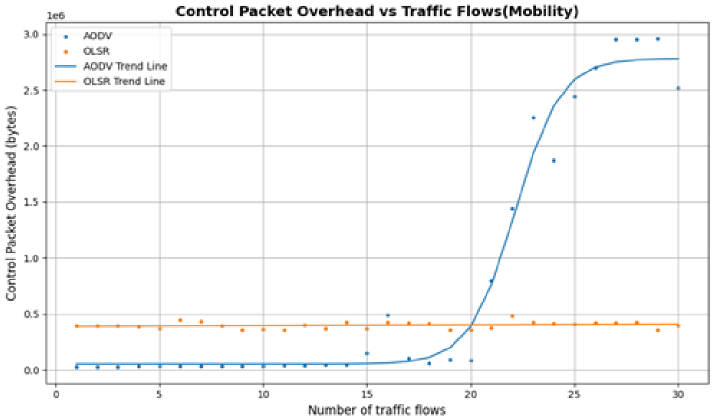


Figure 4-35: *Control packet overhead vs. Number of traffic flows in mobility case*

Discussion

AODV Control Overhead

- In both no-mobility and mobility scenarios, AODV initially performs better for approximately the first 1–18 traffic flows, maintaining lower control traffic overhead compared to OLSR. This is due to its reactive nature, where route discovery is triggered only when required, minimizing unnecessary control packets in low-traffic conditions.
- However, beyond 1–18 traffic flows, the control overhead for AODV increases drastically in both scenarios. This sharp rise is due to the additional route discovery processes triggered by increasing traffic flows. In mobility scenarios, this increase is further amplified by frequent route rediscoveries caused by dynamic topology changes.

OLSR Control Overhead

- OLSR exhibits consistent control overhead across all traffic flows in both no-mobility and mobility scenarios. Its proactive nature, characterized by periodic routing updates, ensures stable performance regardless of traffic flow density or mobility.
- While OLSR's overhead is slightly higher than AODV's for fewer than 10 traffic flows, it becomes the more efficient protocol as traffic density increases, due to its predictable and scalable performance.

Insights

The results highlight the following key observations:

- Low traffic loads: AODV has an advantage in sparse traffic scenarios (up to 10 traffic flows), where its reactive mechanism minimizes unnecessary control overhead.
- High traffic loads: OLSR exhibits better scalability and predictability for networks with moderate to high traffic densities.

- Impact of Mobility: While mobility introduces additional control traffic for AODV due to frequent route rediscoveries, the overall trend remains similar to the no-mobility scenario, with traffic flow density being the dominant factor.

4.5.7 Impact of Varying Velocity on Routing Protocol Performance

In MANETs, the velocity of nodes significantly influences the dynamics of the network topology. As nodes move faster, link breakages and re-establishments occur more frequently, posing challenges for routing protocols.

Scenario Setup

- These settings have been pre-configured in the simulation environment.

Table 4-5: *Scenario settings*

Simulation Parameters	Value
Environment Size	10000 × 5000
Mobility Model	Random Walk
Velocity	Varied from 0 m/s to 100 m/s
Calculation Interval	2 second
Routing Protocol	AODV/OLSR
MAC Protocol	802.11 b
Transmission range	1700 m

- We have considered a 10-node scenario with 10 traffic flows, where simulations were conducted in three separate sets for both AODV and OLSR.
- The control traffic overhead was calculated using the same methodology applied for the no-mobility and mobility scenarios at 4.5.5.
- The results of the simulations are presented in Table 4-6, which shows the averaged control traffic overhead for both protocols at varying velocities.

4.5.8 Velocity cases

The results for the Velocity case of these three sets are as follows:

Table 4-6: *Average control traffic overhead for AODV and OLSR under varying velocity*

	Set 1 (Ctrl Traffic OH)		Set 2 (Ctrl Traffic OH)		Set 3 (Ctrl Traffic OH)		Average	
Velocity	AODV(B)	OLSR(B)	AODV(B)	OLSR(B)	AODV(B)	OLSR(B)	AODV(B)	OLSR(B)
0	33548	314676	33728	508916	33208	422432	33495	415341
10	32336	324080	34964	448776	32844	505620	33381	426159
20	33016	426744	36392	684600	32964	555612	34124	555652
30	32560	513956	42892	452540	36656	527760	37369	498085
40	615268	768320	322956	560448	45332	429436	327852	586068
50	54720	582304	789660	455160	53416	592340	299265	543268
60	988036	328196	1305972	510112	140148	509412	811385	449240
70	302836	535128	722504	510672	746080	301320	590473	449040
80	124608	492072	1989568	296444	110576	253368	741584	347295

Continued on next page

Table 4-6: *(continued)*

Velocity	Set 1 (Ctrl Traffic OH)		Set 2 (Ctrl Traffic OH)		Set 3 (Ctrl Traffic OH)		Average	
	AODV(B)	OLSR(B)	AODV(B)	OLSR(B)	AODV(B)	OLSR(B)	AODV(B)	OLSR(B)
90	1281244	616508	2920076	313044	81160	429284	1427493	452945
100	1249232	876372	2055652	386924	2607460	386260	1970781	549852

The averaged results from the three sets provide a comparison of the control traffic overhead for the two protocols under varying velocity conditions.

Plot:

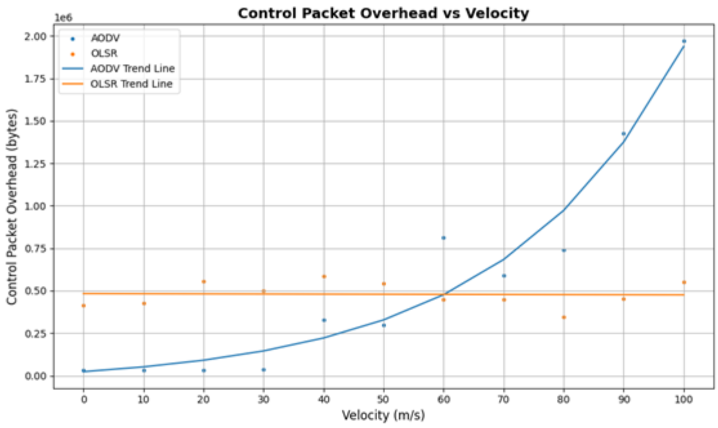


Figure 4-36: *Control traffic overhead for AODV and OLSR under varying velocity*

Discussion

AODV Control Overhead

- Low Velocity (0–20 m/s): At lower velocities, the network topology remains relatively stable, leading to fewer route rediscoveries. AODV maintains a low and gradually increasing control traffic overhead in this range.
- High Velocity (20–100 m/s): As velocity increases, frequent link breakages due to rapid topology changes necessitate repeated route rediscovery processes. This results in a sharp rise in AODV's control overhead, especially beyond 50 m/s.

OLSR Control Overhead

- Stable Performance Across Velocities: OLSR exhibits consistent control overhead across all velocity levels. This is due to its proactive routing approach, where periodic updates maintain routing tables regardless of node velocity.
- Minimal Impact of Velocity: Even at the highest velocity (100 m/s), OLSR's overhead remains relatively constant, highlighting its robustness in handling dynamic topologies.

Insights

The results highlight the following key observations:

- Performance at low velocity: AODV's reactive nature minimizes control traffic overhead, making it more efficient in networks with low or limited mobility.
- Performance at high velocity: OLSR's proactive updates ensure stable and predictable overhead, making it better suited for highly dynamic environments.

4.6 Multiple MANETS

Open NetSim and Select Examples→Mobile Ad hoc Networks→Multiple MANETs then click on the tile in the middle panel to load the example as shown in below screenshot Figure 4-17.

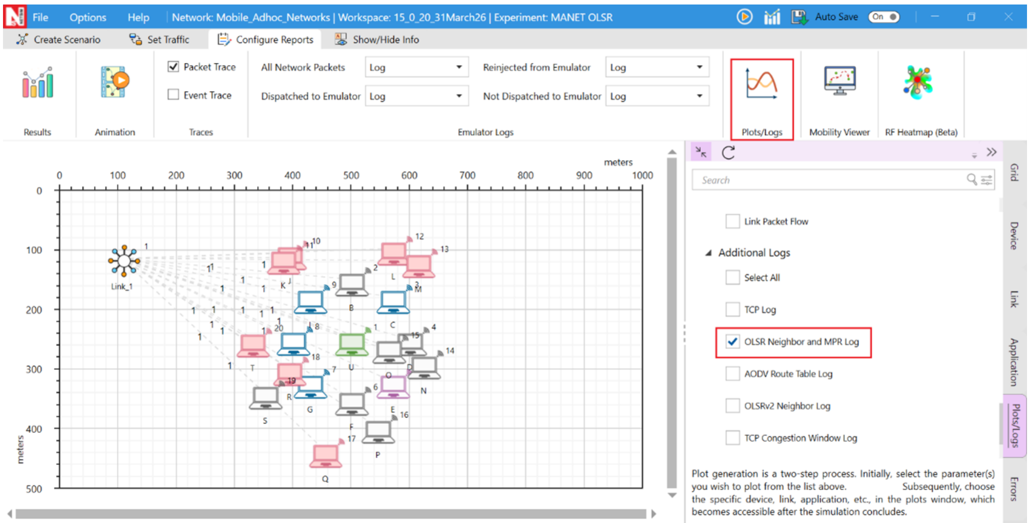


Figure 4-37: *List of scenarios for the example of Multiple-MANETs*

Multiple MANETs allows users to interconnect two or more MANETs using a bridge node. Click and drop wireless nodes, Ad hoc links and bridge node onto the grid environment and connect wireless nodes to ad hoc links to form two different MANETs using ad hoc links. Further, connect the two MANETs using a bridge node as shown below Figure 4-18.

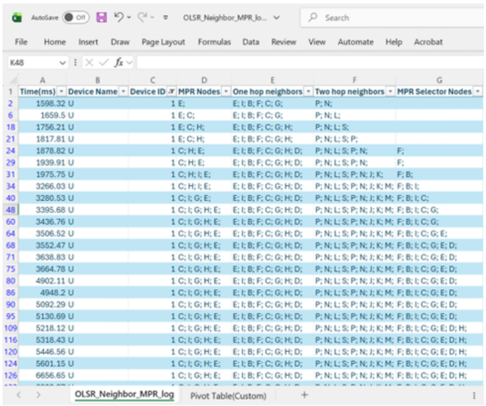


Figure 4-38: *Network set up for studying the Multiple-MANETs*

4.6.1 Network Settings

1. Grid length: 500m×250m from grid setting property panel on the right. This needs to be done before any device is placed on the grid.
2. A network scenario is designed in the NetSim GUI, comprising four wireless nodes and one bridge node, with two ad hoc links from the Interconnected MANETs module.
3. To configure any properties in the nodes, click on the node, expand the property panel on the right side, and change the properties as mentioned below.
4. The Medium access protocol was set to DCF in Interface (Wireless)→ Datalink layer of all wireless nodes and bridge node (Interface 1 and Interface 2).

5. The routing protocol in the network layer is set to AODV for all nodes. As this is a global property, changing it on one node will affect all nodes.
6. Create a CBR application from wireless node 1 to wireless node 5 from the set traffic tab in the ribbon on top. Click on the created application, and in the right-side property panel, set the transport protocol to UDP, keeping the other application properties as default.
7. Enable packet trace from the configure reports tab in ribbon on top.
8. Run simulation for 10 seconds.

4.6.2 Output

After simulation, open packet trace from simulation results window and filter Control Packet Type/App Name to App1 CBR and Packet Id to 1. In the below screenshot, users can observe that the packets from source node-1 are going to destination node-5 via bridge node-3.

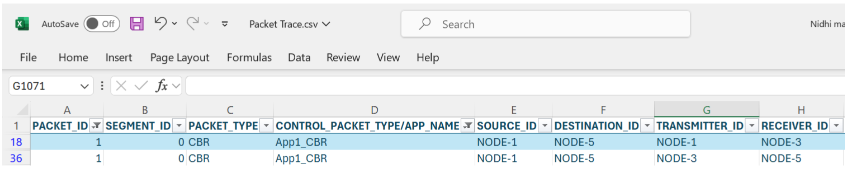


Figure 4-39: *Packet transmitting from Source Node-1 to Destination Node-5 via Bridge Node-3 in Packet Trace.*

4.7 Energy consumption in MANETs

In this experiment, we aim to analyze the per-packet energy consumption for various types of packets, including data packets of different sizes, WLAN ACKs, and MANET control packets, across both DSR and AODV protocols.

Open NetSim and Select Examples→ Mobile Ad hoc Networks →Energy consumption in MANET then click on the tile in the middle panel to load the example as shown in below screenshot.

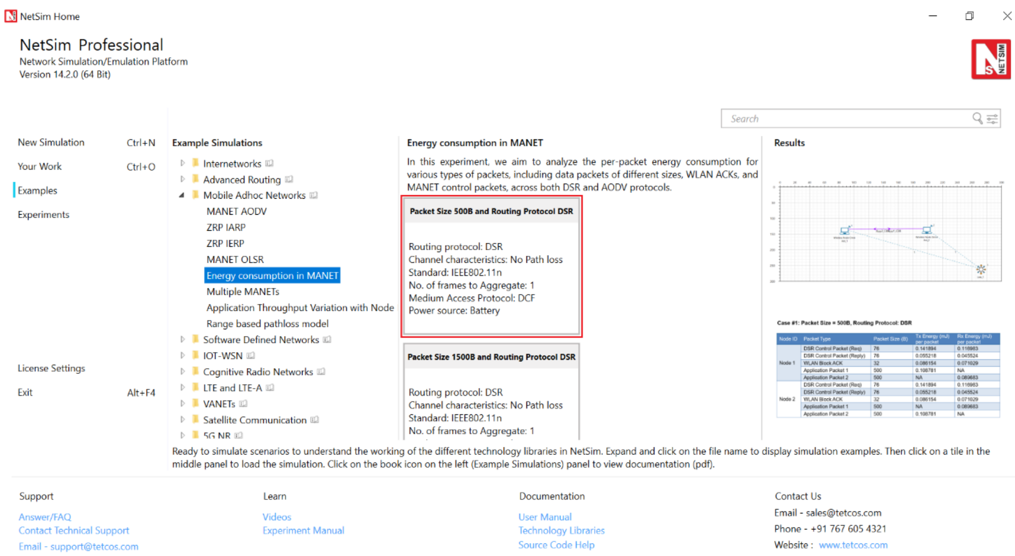


Figure 4-40: *List of scenarios for the example of Energy consumption in MANET.*

4.7.1 Network Setup

The following network diagram illustrates what the NetSim UI displays when you open the example configuration file.

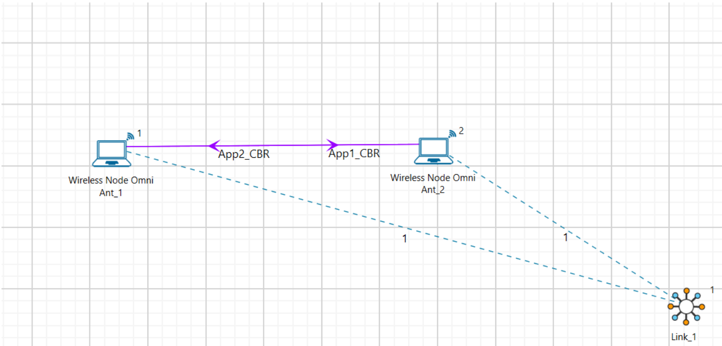


Figure 4-41: *Network setup for analyzing the energy consumption in MANETs.*

- The scenario comprises of two wireless node omni ants, wireless node omni ant1 and wireless node omni ant2.
- Wireless node omni ant1 sends data to wireless node omni ant2, and wireless node omni ant2 sends data to wireless node omni ant1.
- Set grid length to 400m×200m from grid setting property panel on the right. This needs to be done before any device is placed on the grid.
- Click on wireless node, expand the property panel on the right and set the following properties under different layers.

Table 4-7: *Wireless node Omni Ant properties configured in NetSim.*

Device Properties	Value
Position layer properties	
Mobility Model	No Mobility
Network layer properties	
Routing Protocol	DSR/AODV
Interface(Wireless) properties	
Datalink layer properties	
Medium Access Protocol	DCF
Physical layer properties	
Standard	IEEE802.11n
Number of Frames to Aggregate	1
Tx & Rx antenna counts	1 × 1
Power Source	Battery

Table 4-8: *Battery model properties configured in NetSim.*

Battery Properties	Value
Energy harvesting	Off
Initial energy (mAh)	300
Transmitting current	316.7
Idle mode current	227
Voltage (V)	3.6
Receiving current	261.1

Table 4-9: *Link properties configuration.*

Link Properties	Value
Channel characteristics	No pathloss

Table 4-10: *Application configured from wireless node omni Ant1 to wireless node omni ant2 and wireless node omni ant2 to wireless node omni ant1 for 2 cases, with packet size as 420B and 1420B. These are the application layer packet sizes and on adding overheads the packet sizes are 500B and 1500B respectively at the PHY layer.*

Application Properties	Value
Source Id	1 / 2
Destination Id	2 / 1
Packet size (B)	420 / 1420 / 428
Inter arrival time	20000
Mean generation rate (kbps)	168 / 568 / 171

- Click on the set traffic tab in the top ribbon/toolbar and create a CBR application as per the below settings.
- Enable the Packet trace under config reports tab on the top.
- Enable the IEEE 802.11 Radio measurement and Energy log under Network log as shown below.

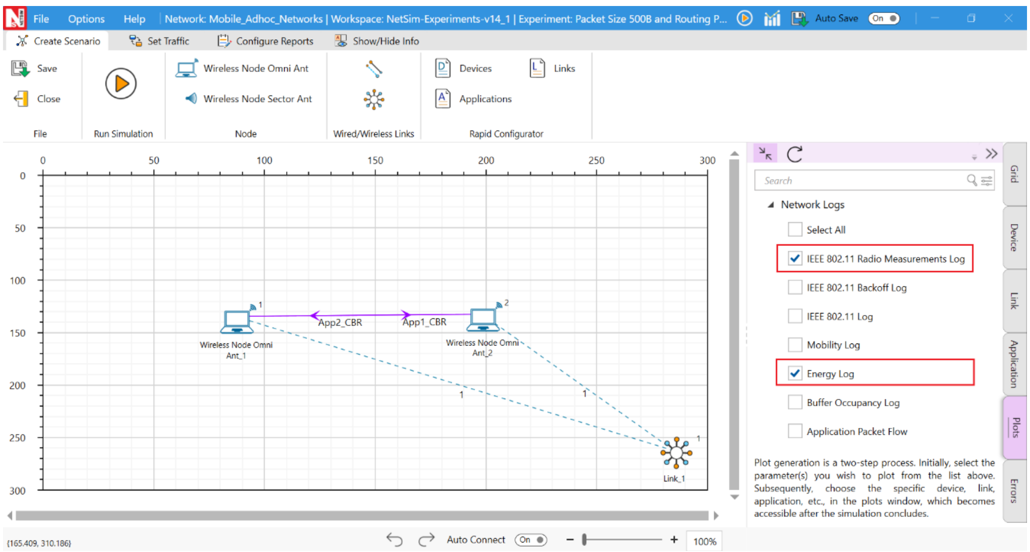


Figure 4-42: *Enabling IEEE 802.11 Radio measurement and Energy log.*

- Run the simulation for 100 seconds.

4.7.2 Energy Consumption

The energy consumption is given by

$$\text{ConsumedEnergy } (J) = V \text{ [Volts]} \times I \text{ [Amps]} \times t \text{ [sec]}$$

where V is the battery voltage, I is the current drawn and t is the time for which the node is in a particular mode.

This can be computed for each packet and for each mode using NetSim's energy log. The formula to be used is

$$\text{ConsumedEnergy (mJ)} = \frac{\text{Voltage } [V] \times \text{ModeCurrent [mA]} \times (\text{CurrentTime } (\mu s) - \text{ModeChangeTime } (\mu s))}{10^6}$$

where current time minus mode-change-time is the time for which the node is in a particular mode.

4.7.3 Energy consumption calculations

In the results window, open packet trace and Energy log file as shown below.

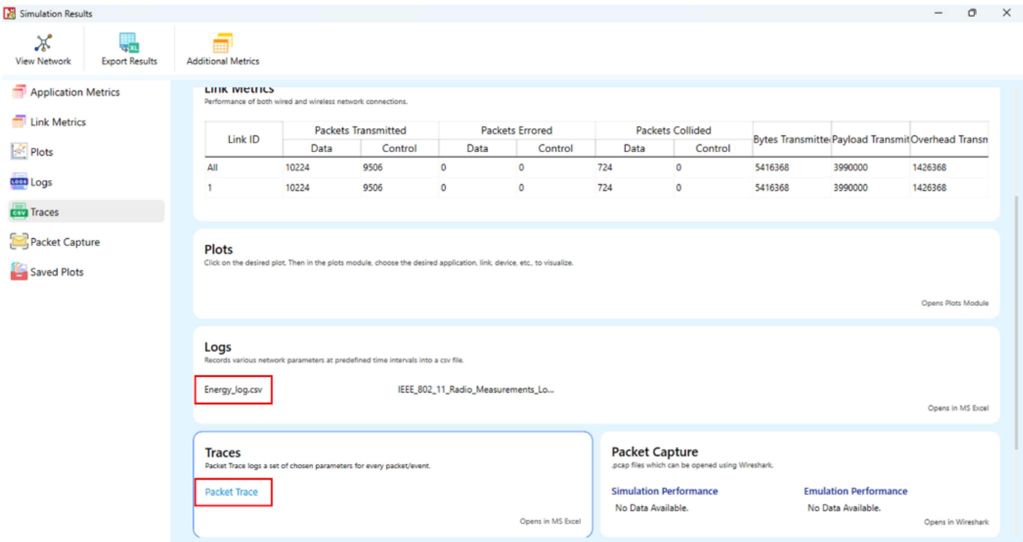


Figure 4-43: *Open Energy log file and packet trace from Results tab.*

Open Energy log file and Filter out previous mode to TRX on busy and RX on busy in Energy log as shown below.

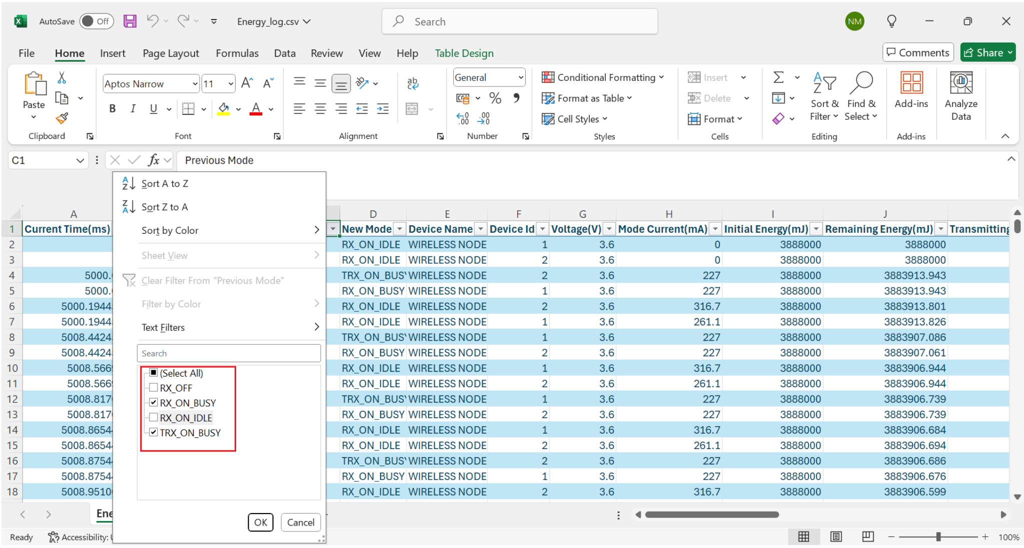


Figure 4-44: *Filter out RX on busy and TRX on busy under previous mode in Energy log file.*

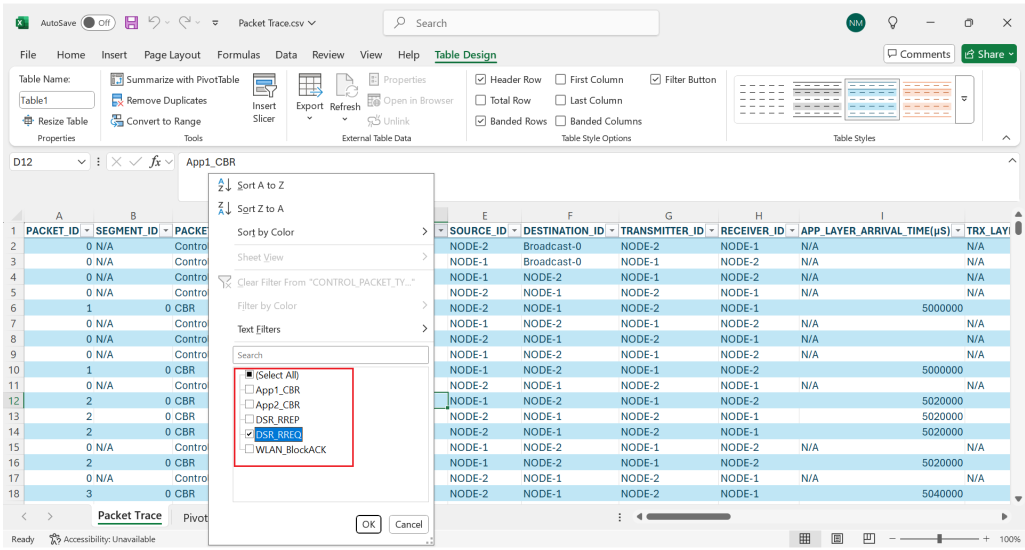


Figure 4-45: *Filter out the DSR RREQ under Control Packet Type/App Name in packet trace.*

To calculate the energy consumption for different packet types, first filter out the packet type in packet trace and note the PHY LAYER ARRIVAL TIME (μs) column value and cross-reference with Mode Switch Time(ms) column in the energy log file for TRX ON BUSY/RX ON BUSY case as shown below.

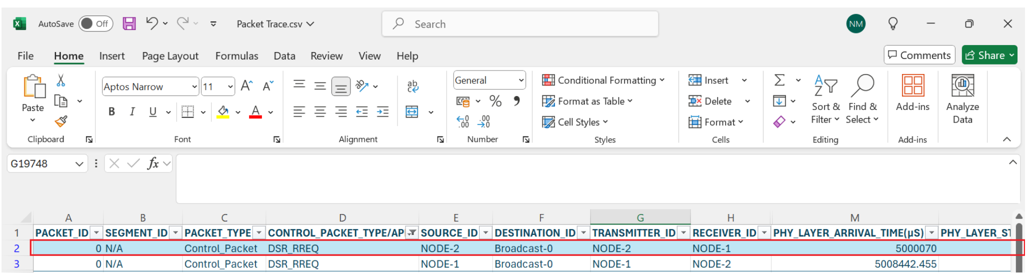
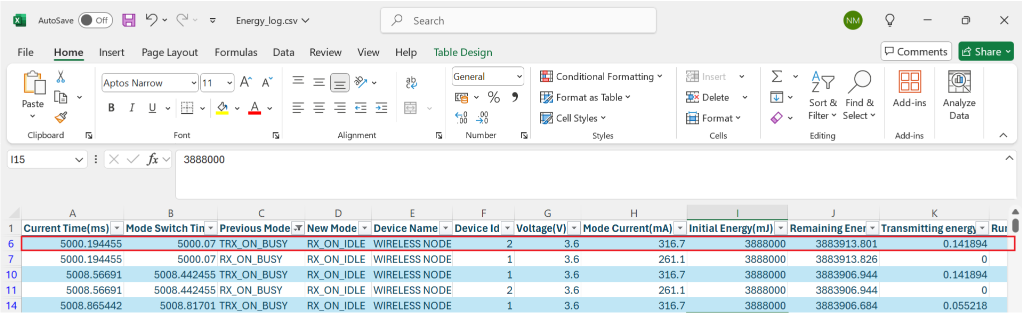


Figure 4-46: *Filter out packet type in packet trace.*



	Current Time(ms)	Mode Switch Tin	Previous Mode	New Mode	Device Name	Device Id	Voltage(V)	Mode Current(mA)	Initial Energy(mJ)	Remaining Ener	Transmitting energy	Rur
6	5000.194455	5000.07	TRX_ON_BUSY	RX_ON_IDLE	WIRELESS NODE	2	3.6	316.7	3888000	3883913.801	0.141894	
7	5000.194455	5000.07	RX_ON_BUSY	RX_ON_IDLE	WIRELESS NODE	1	3.6	261.1	3888000	3883913.826	0	
10	5008.56691	5008.442455	TRX_ON_BUSY	RX_ON_IDLE	WIRELESS NODE	1	3.6	316.7	3888000	3883906.944	0.141894	
11	5008.56691	5008.442455	RX_ON_BUSY	RX_ON_IDLE	WIRELESS NODE	2	3.6	261.1	3888000	3883906.944	0	
14	5008.865442	5008.81701	TRX_ON_BUSY	RX_ON_IDLE	WIRELESS NODE	1	3.6	316.7	3888000	3883906.684	0.055218	

Figure 4-47: *Filter out mode to TRX ON BUSY and RX ON BUSY in Energy log. Record the Phy Layer Arrival Time from packet trace and cross-reference with Mode Switch Time in Energy log.*

In the calculations below, the voltage and mode current are user inputs while current time and mode switch time are recorded in the energy log file. The packet trace is only used to determine the type of packet (Route request, Data, WLAN ACK etc.).

- DSR Route Request
- Transmit Energy

$$\text{Energy (mJ)} = \frac{\text{Voltage}(V) \times \text{ModeCurrent(mA)} \times (\text{CurrentTime} - \text{ModeChangeTime})(\text{ms})}{10^3} \tag{11}$$

$= 3.6V \times 316.7\text{mA} \times (5008.5669 - 5008.4424) \times 10^{-3}$

$= 0.141894$

- Receive Energy

$$\text{Energy (mJ)} = \frac{\text{Voltage}(V) \times \text{ModeCurrent(mA)} \times (\text{CurrentTime} - \text{ModeChangeTime})(\text{ms})}{10^3} \tag{12}$$

$= 3.6V \times 261.1\text{ mA} \times (5000.19446 - 5000.07) \times 10^{-3}$

$= 0.116983$

- DSR Route Reply
- Transmit Energy

$$\text{Energy (mJ)} = \frac{\text{Voltage}(V) \times \text{ModeCurrent(mA)} \times (\text{CurrentTime} - \text{ModeChangeTime})(\text{ms})}{10^3} \tag{13}$$

$= 3.6V \times 316.7\text{mA} \times (5008.865442 - 5008.81701) \times 10^{-3}$

$= 0.055218$

- Receive Energy

$$\text{Energy (mJ)} = \frac{\text{Voltage}(V) \times \text{ModeCurrent(mA)} \times (\text{CurrentTime} - \text{ModeChangeTime})(\text{ms})}{10^3} \tag{14}$$

$= 3.6V \times 261.1 \text{ mA} \times (5010.473342 - 5010.42491) \times 10^{-3}$

$= 0.045524$

- Application (Data) Packets, 500B
- Transmit Energy

$$\text{Energy (mJ)} = \frac{\text{Voltage}(V) \times \text{ModeCurrent(mA)} \times (\text{CurrentTime} - \text{ModeChangeTime})(\text{ms})}{10^3} \quad (15)$$

$= 3.6V \times 316.7\text{mA} \times (5009.21652 - 5009.121108) \times 10^{-3}$

$= 0.1087811$

- Receive Energy

$$\text{Energy (mJ)} = \frac{\text{Voltage}(V) \times \text{ModeCurrent(mA)} \times (\text{CurrentTime} - \text{ModeChangeTime})(\text{ms})}{10^3} \quad (16)$$

$= 3.6V \times 261.1 \text{ mA} \times (5010.76442 - 5010.669008) \times 10^{-3}$

$= 0.089683$

- WLAN Block ACK Packets
- Transmit Energy

$$\text{Energy (mJ)} = \frac{\text{Voltage}(V) \times \text{ModeCurrent(mA)} \times (\text{CurrentTime} - \text{ModeChangeTime})(\text{ms})}{10^3} \quad (17)$$

$= 3.6V \times 316.7\text{mA} \times (5009.302086 - 5009.22652) \times 10^{-3}$

$= 0.086154$

- Receive Energy

$$\text{Energy (mJ)} = \frac{\text{Voltage}(V) \times \text{ModeCurrent(mA)} \times (\text{CurrentTime} - \text{ModeChangeTime})(\text{ms})}{10^3} \quad (18)$$

$= 3.6V \times 261.1 \text{ mA} \times (5008.951008 - 5008.875442) \times 10^{-3}$

$= 0.071029$

4.7.4 Case#1: Results and discussion

Packet Size = 500B, Routing Protocol: DSR

Table 4-11: *Tx and Rx energy consumption per packet for 500-byte packet size and DSR routing protocol.*

Node ID	Packet Type	Size (B)	Tx Energy (mJ)	Rx Energy (mJ)
Node 1	DSR Ctrl Pkt (Req)	76	0.1418936	0.1169827
	DSR Ctrl Pkt (Reply)	76	0.0552183	0.0455241
	WLAN Block ACK	32	0.0861543	0.0710290
	App Packet 1	500	0.1087811	NA
	App Packet 2	500	NA	0.0896835
Node 2	DSR Ctrl Pkt (Req)	76	0.1418936	0.1169827
	DSR Ctrl Pkt (Reply)	76	0.0552183	0.0455241
	WLAN Block ACK	32	0.0861543	0.0710290
	App Packet 1	500	NA	0.0896835
	App Packet 2	500	0.1087811	NA

4.7.5 Case #2: Results and discussion

Packet Size = 1500B, Routing Protocol: DSR

Table 4-12: *Tx and Rx energy consumption per packet for 1500-byte packet size and DSR routing protocol.*

Node ID	Packet Type	Size (B)	Tx Energy (mJ)	Rx Energy (mJ)
Node 1	DSR Ctrl Pkt (Req)	76	0.1418936	0.1169827
Node 1	DSR Ctrl Pkt (Reply)	76	0.0552183	0.0455241
Node 1	WLAN Block ACK	32	0.0861543	0.0710290
Node 1	App Packet 1	1500	0.2351098	NA
Node 1	App Packet 2	1500	NA	0.1938339
Node 2	DSR Ctrl Pkt (Req)	76	0.1418936	0.1169827
Node 2	DSR Ctrl Pkt (Reply)	76	0.0552183	0.0455241
Node 2	WLAN Block ACK	32	0.0861543	0.0710290
Node 2	App Packet 1	1500	NA	0.1938339
Node 2	App Packet 2	1500	0.0861543	NA

- DSR Route Request is a broadcast packet.
- Broadcast packet is sent at "broadcast" rate which uses the lowest rate (MCS).
- Since this packet is sent at the lowest rate, the Transmission time is higher leading to higher energy consumption.
- DSR Route reply is a unicast packet.
- This is sent at "unicast" rate. This rate (MCS) is chosen per the Wi-Fi MCS-Rx Power tables. In this case it is MCS 7.
- Transmission time is lower than DSR Route Request leading to lower energy consumption, even though the RREQ and RREP packets are of the same size.
- We see that the application and WLAN ACK packets have the same transmit and received energies for both nodes.
- Compared to case #1, in case #2, the packet size is three times larger (1500B vs. 500B), but the energy consumption isn't proportionally higher (i.e., it is not three times more). This is because the difference in the total transmission times is not a factor of three.

- Recall that in Wi-Fi

$$\text{TotalTransmissionTime}\ (s) = \text{Pkt. TransmissionTime} + \text{PreambleTime}(s) \tag{19}$$

We know that

$$\text{Pkt. TransmissionTime}\ (\mu s) = \text{ceil}\left(\frac{\text{Pkt.Size}(B)}{\text{DataRate(Mbps)}}\right) \tag{20}$$

- While the packet transmission time is three times longer than before, the preamble time remains constant at 40 μs in both cases.
- For a packet size of 500B given a data rate of 72.2 Mbps

$$\text{Pkt. TransmissionTime}\ (\mu s) = \text{ceil}\left(\frac{500 \times 8}{72.2}\right) = 55.402 \tag{21}$$

$$\text{TotalTransmissionTime}\ (\mu s) = 55.402 + 40 = 95.402 \tag{22}$$

- For packet size = 1500B

$$\text{Pkt. TransmissionTime}\ (\mu s) = \text{ceil}\left(\frac{1500 \times 8}{72.2}\right) = 166.205 \tag{23}$$

$$\text{TotalTransmissionTime}\ (\mu s) = 166.205 + 40 = 206.205 \tag{24}$$

- We can see that the total transmission time is only about 2.16 times higher. Therefore, the total energy consumption is also 2.16 times higher than the previous scenario, and not three times higher.

4.7.6 Case #3: Results and discussion

Packet Size = 500B, Routing Protocol: AODV

We perform similar energy calculations for AODV and obtain the table below.

Table 4-13: *Tx and Rx energy consumption per packet for 500-byte packet size and AODV routing protocol.*

Node ID	Packet Type	Size (B)	Tx Energy (mJ)	Rx Energy (mJ)
Node 1	AODV Ctrl Pkt (Req)	88	0.1570949	0.1295152
Node 1	AODV Ctrl Pkt (Reply)	84	0.0562284	0.0463569
Node 1	WLAN Block ACK	32	0.0861543	0.0710290
Node 1	App Packet 1	500	0.1087811	NA
Node 1	App Packet 2	500	NA	0.0896835
Node 2	AODV Ctrl Pkt (Req)	88	0.1570949	0.1295152
Node 2	AODV Ctrl Pkt (Reply)	84	0.0562284	0.0463569
Node 2	WLAN Block ACK	32	0.0861543	0.0710290
Node 2	App Packet 1	500	NA	0.0896835
Node 2	App Packet 2	500	0.1087811	NA

- AODV Route Request is a broadcast packet.
- Broadcast packet is sent at "broadcast" rate which is the lowest MCS.
- Transmission time is higher leading to higher energy consumption.
- AODV Route reply is a unicast packet.
- This is sent at Unicast rate which is dependent on the received power. In this case it is sent at MCS 7 (QAM 64).
- We see that the application and WLAN ACK packets have the same transmit and receive energies as in DSR.
- Similar calculations as done for DSR can be carried out to verify the results.

Energy consumption plot:

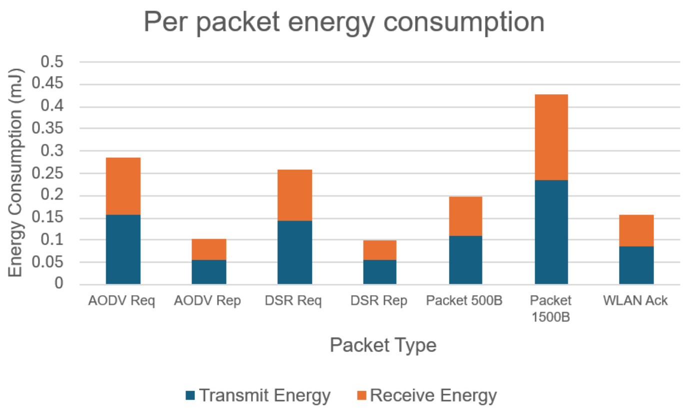


Figure 4-48: *Energy consumption plot for different packet types.*

4.8 Application throughput variation with node mobility

Objective

To simulate and analyze how application throughput varies as the node moves away. This analysis is done for 802.11n standard.

Open NetSim and Select Examples→Mobile Ad hoc Networks→Application Throughput Variation with Node Mobility then click on the tile in the middle panel to load the example as shown in below screenshot Figure 4-24.

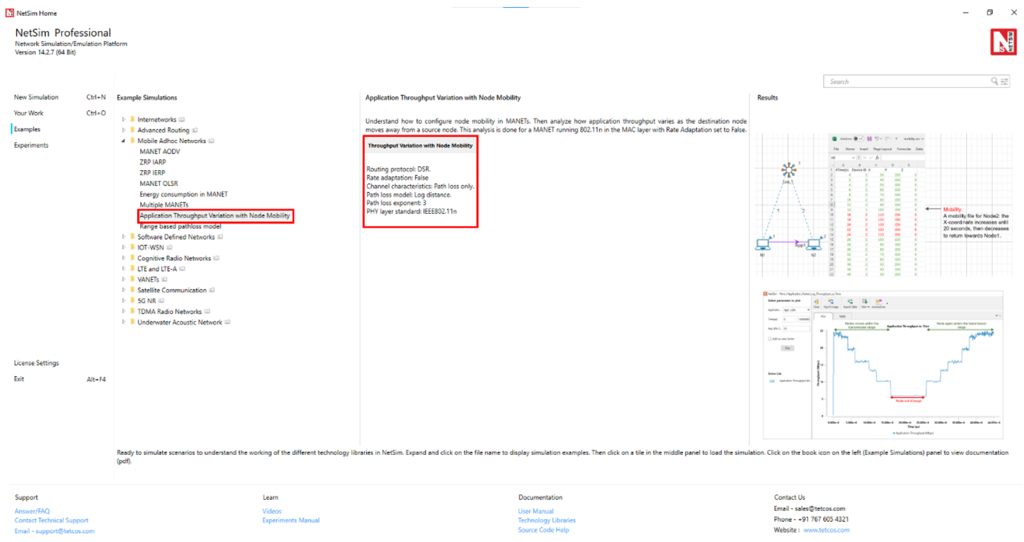


Figure 4-49: *List of scenarios for the example of Application Throughput Variation with Node Mobility*

The following network diagram illustrates what the NetSim UI displays when you open the example configuration file see Figure 4-25.

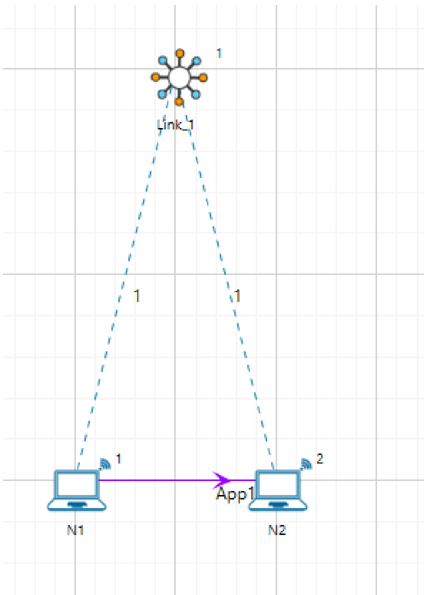


Figure 4-50: *Network set up for studying the Application Throughput variation with Node mobility*

4.8.1 Network Settings

1. The device coordinates were set as follows. To configure the below, click on device, expand the property panel on right and change the below in position layer.

Table 4-14: *Devices Position*

Device	X-Coordinate	Y-Coordinate
N1	10	150
N2	30	150

2. Set grid length to 300m×150m from grid setting property panel on the right. This needs to be done before any device is placed on the grid.
3. To configure any properties in the nodes, click on the node, expand the property panel on the right side, and change the properties as mentioned below.
4. IEEE standard was set to 802.11n in Interface (Wireless) ▷ Physical layer of both the wireless nodes.
5. The Physical layer properties were set as shown in Table 4-2.

Table 4-15: *Detailed Network Parameters*

Interface Parameters	Value
Standard	IEEE802.11n
No. of Frames to Aggregate	1
Transmitter Power	100mW
Bandwidth	20MHz
Standard Channel	1 (2412MHz)
Reference distance (d0)	1m
Guard Interval	400ns
Antenna	
Antenna height	1m
Antenna gain	0
Transmitting antennas	1
Receiving antennas	1

6. The Medium Access Protocol was set to DCF in Interface (Wireless)→ Datalink layer of both wireless nodes.
7. Click on N1 and expand right-hand side property panel and go to Network layer, Enable Static IP Route and Configure Static Route via GUI as shown below screenshot Figure 4-26.

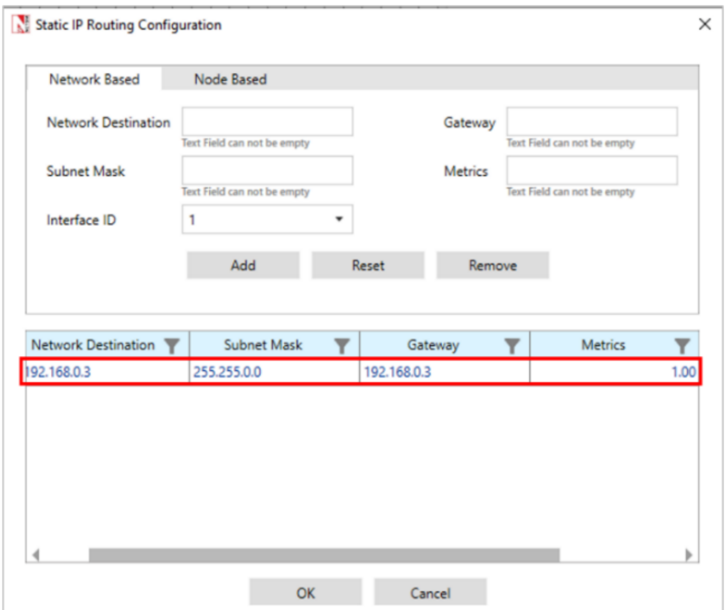


Figure 4-51: *Static IP Route configuration window*

8. Rate Adaptation was set as False in Interface (Wireless) → Datalink layer of both wireless nodes.

9. Click on link and expand right-hand side property panel and set the Channel characteristics as: Path loss only; Path loss model: Log Distance; Path loss exponent: 3 under medium property.
10. Click on the N1 and N2 devices and expand right-hand side property panel and set the mobility model to No Mobility in N1 and File Based Mobility in N2.
11. Click on set traffic tab and configure Unicast CBR application from N1 to N2. Click on the created application, and in the right-side property panel, set the transport protocol to UDP and the start time to 0s. Set the packet size to 1460 bytes and Inter Arrival Time to 476.2 microseconds, which gives a Generation Rate of 25Mbps.
12. Set application start time as 0 sec.
13. The Transport protocol was set to UDP.
14. Enable the Application throughput vs time plot and SNR vs time plot under Plots in Configure reports.
15. Run the simulation for 45 seconds.
16. Open the Application throughput vs. Time plot and uncheck the Accelerate plotting and observe the below plot.

File based mobility file

Table 4-16: *File based mobility file that models the movement of N2. The X co-ordinate is incrementally increased till the 20th second ensuring N2 moves away from node1. Subsequently, the X-coordinate is decreased to facilitate N2's return towards N1.*

Time(s)	Node ID	X (m)	Y (m)	Z (m)
0	2	30	100	0
2	2	40	100	0
4	2	50	100	0
6	2	60	100	0
8	2	70	100	0
10	2	80	100	0
12	2	90	100	0
14	2	100	100	0
16	2	110	100	0
18	2	120	100	0
20	2	130	100	0
22	2	120	100	0
24	2	110	100	0
26	2	100	100	0
28	2	90	100	0
30	2	80	100	0
32	2	70	100	0
34	2	60	100	0
36	2	50	100	0
38	2	40	100	0
40	2	30	100	0

4.8.2 Output

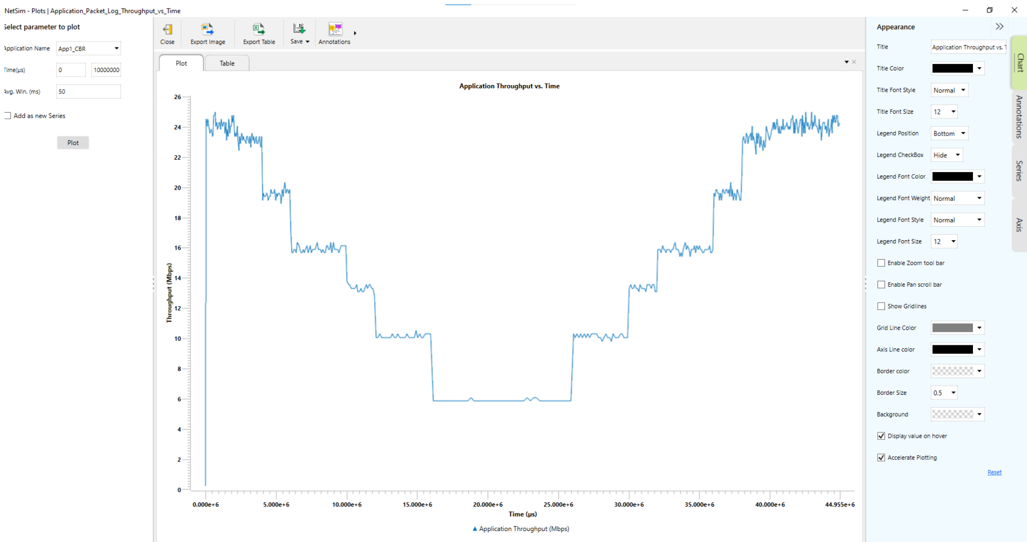


Figure 4-52: *Plot of Application throughput vs. time.*

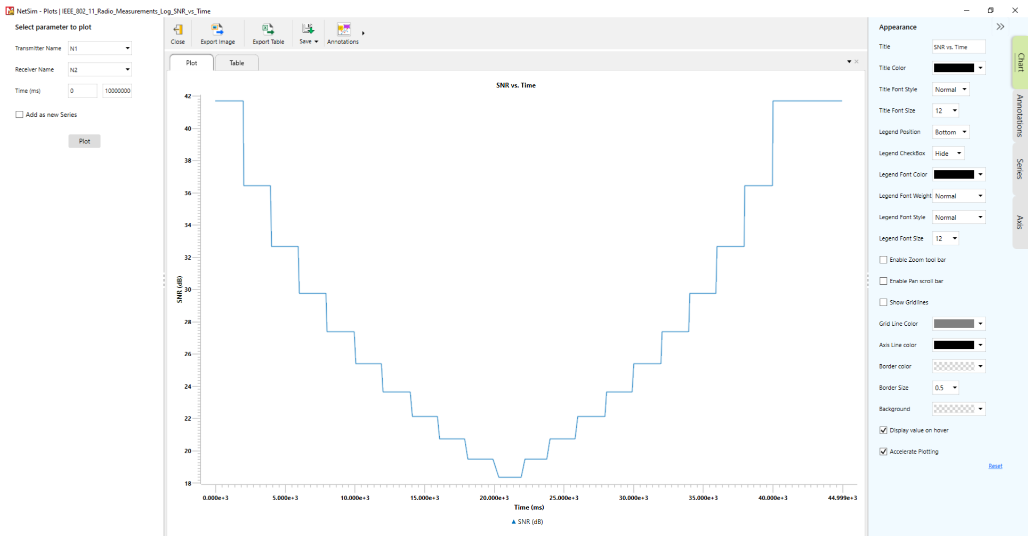


Figure 4-53: *Plot of SNR vs. Time.*

4.8.3 Inference

We can also observe the SNR vs. Time plot obtained after the simulation. The SNR is high initially and gradually drops as N2 moves away from N1. After N2 moves back towards the transmitter around the 20th second, we observe an increase in the SNR. The pathloss exponent in the log distance pathloss model was set to 3.0.

Recall that throughput is proportional to SNR. We observe that the Application throughput drops from 25 Mbps to 20 Mbps at around 4 seconds (the distance at this time is 50 m), and then to 15.8 Mbps at 6.5 seconds (the distance at this time is 70 m) and to 10.2 Mbps at 12 seconds (the distance at this time is 90 m) and then to 5.8 Mbps at 20 seconds (the distance at this time is 130 m). After the 20th second N2 starts moving back towards N1 and we can see the increase in throughput.

4.9 Performance of range based pathloss model in MANETs

Open NetSim and Select Examples→Mobile Ad hoc Networks→Range Based pathloss model then click on the tile in the middle panel to load the example as shown in below screenshot Figure 4-28.

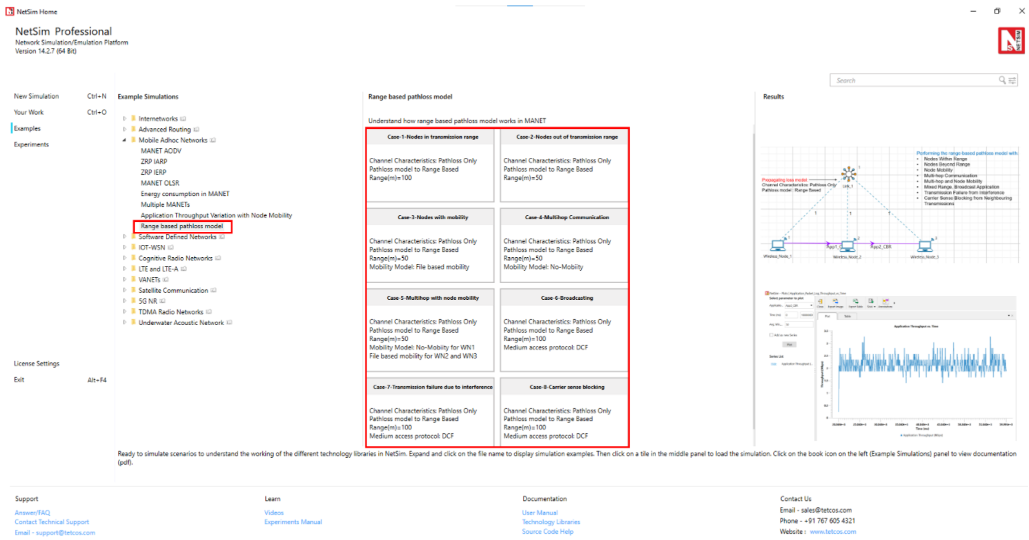


Figure 4-54: *List of scenarios for the example of Range based pathloss model.*

4.9.1 Introduction

The propagation loss depends only on the distance (range) between transmitter and receiver. There is a single Range attribute that determines the path loss.

This is not a real-world loss model but a theoretical model useful for experimentation. Receivers at or within Range meters see a 0 dB pathloss. Hence received power equals transmit power. Receivers beyond Range see a 1000 dB pathloss. Hence received power will be close to −1000 dBm i.e., zero in linear units.

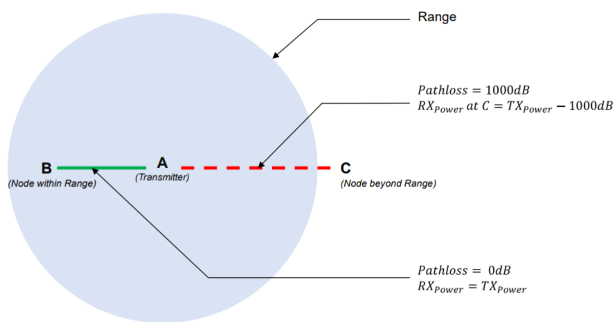


Figure 4-55: *This figure explains a typical range based pathloss model. In this example, Node A and B are in transmission range with each other which is denoted by a blue circle where the pathloss is 0dB i.e, successful transmission. And Node C is beyond the range i.e, pathloss is 1000dB all packets are errored and dropped. In NetSim, users must specify the range of the node in meters in the links.*

The Range-Based Path Loss Model can be used in networks such as Internetworks, MANET, VANET, TDMA, Pure ALOHA, Slotted ALOHA, Cognitive Radio, IoT, WSN, and UWAN.

In this example, we will study the different cases in Range based Pathloss using Mobile Ad hoc networks.

4.9.2 Case 1: Range Based Pathloss. Nodes Within Transmission Range.

The following network diagram illustrates what the NetSim UI displays when you open the example configuration file.

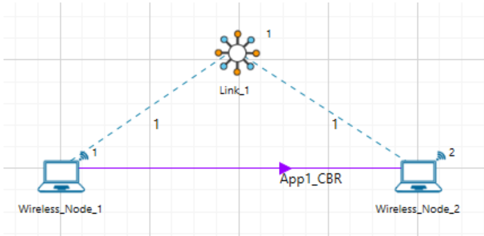


Figure 4-56: *For studying the range based pathloss model with range*

Network Settings

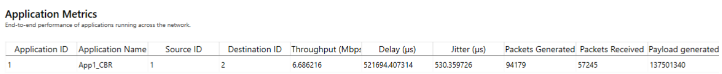
1. Set grid length as 400 × 200 from grid setting property panel on the right. This needs to be done before any device is placed on the grid.
2. Drop 2 wireless nodes and 1 Ad hoc link in Grid environment.
3. Device placements of wireless nodes are:

Table 4-17: *Device Placements*

Device	X-Coordinate	Y-Coordinate
Wireless Node-1	100	150
Wireless Node-2	180	150

4. Click on link and expand right-hand side property panel and set Channel Characteristics: Pathloss, Pathloss model to Range based, Range(m)=100 under medium property.
5. Clicking on Wireless node and expand right-hand side property panel and set, Mobility Model: No-Mobility, for both nodes under position property.
6. Click on the set traffic tab present in the top ribbon. Create a CBR Application with 11Mbps generation rate (Set Packet size: 1460, Inter Arrival Time: 1061.81 μs) from wireless node-1 to wireless node-2. Set Transport protocol to UDP and start time to zero.
7. Enable throughput vs time plot under Application and link performance by clicking on plots/logs tab in right panel.
8. Run the simulation for 100 seconds.

4.9.3 Output and Plot


Application Metrics
End-to-end performance of applications running across the network.

Application ID	Application Name	Source ID	Destination ID	Throughput (Mbps	Delay (µs)	Jitter (µs)	Packets Generated	Packets Received	Payload generated
1	App1_CBR	1	2	6.686216	521694.407314	530.359726	94179	57245	137501340

Figure 4-57: *Application Metrics window.*

In Simulation result window, click on Throughput vs Time plot under Application performance. After the plot window is displayed, click on the plot option.

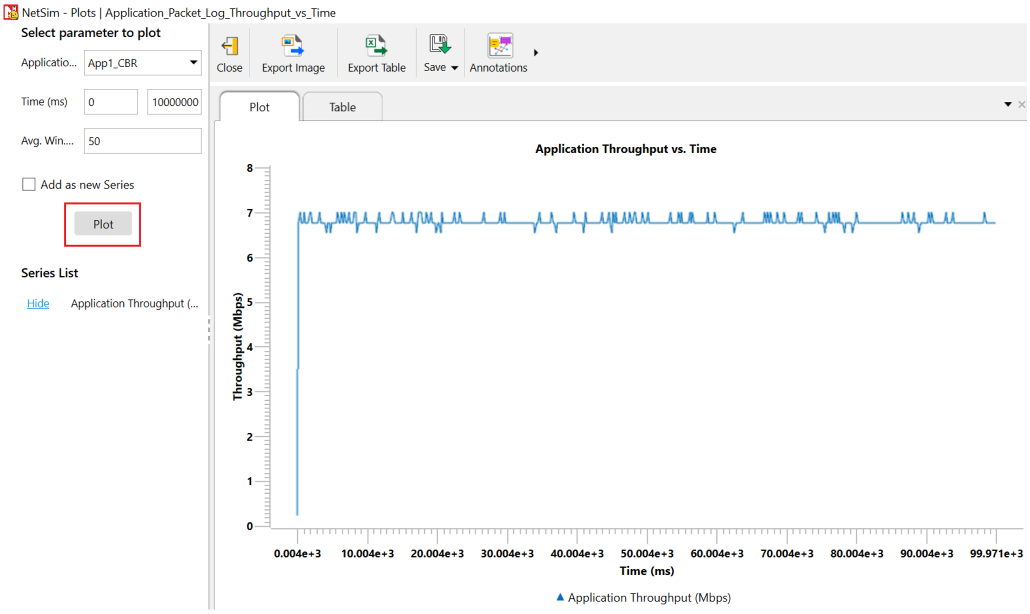


Figure 4-58: *Application throughput plot.*

Discussion

The above results show continuous data transmission and constant throughput throughout the simulation. This occurs because Wireless Node-2 is within the transmission range of Wireless Node-1. Specifically, the range-based parameter is set to 100 meters, and Wireless Node-2 is positioned 80 meters away from Wireless Node-1.

4.9.4 Case 2: Range Based Pathloss. Nodes Beyond Transmission Range.

The following network diagram illustrates what the NetSim UI displays when you open the example configuration file.

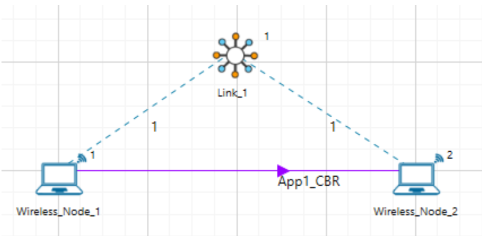


Figure 4-59: *For studying the range based pathloss model without range*

Network Settings

1. Set Grid length as 400 × 200 from grid setting property panel on the right. This needs to be done before any device is placed on the grid.
2. Drop 2 wireless nodes and 1 Ad hoc link in Grid environment.
3. Device placements of wireless nodes are:

Table 4-18: *Device placements*

Device	X-Coordinate	Y-Coordinate
Wireless Node-1	100	150
Wireless Node-2	180	150

4. Click on link and expand right-hand side property panel and set channel characteristics: Pathloss, Pathloss model to Range based, Range(m)=50 meters under medium property.
5. Click on wireless node and expand right-hand side property panel and set Mobility model: No-mobility, for both nodes under position property.
6. Click on the set traffic tab present in the top ribbon, create a CBR Application with 11Mbps generation rate (Set Packet size: 1460, Inter Arrival Time: 1061.81 μs) from wireless node-1 to Wireless node-2. Set Transport protocol to UDP and start time to zero.
7. In NetSim GUI Application and link throughput vs time plot should be enabled.
8. Run the Simulation for 100 seconds.

4.9.5 Output and Plot

Application Metrics

End-to-end performance of applications running across the network.

Application ID	Application Name	Source ID	Destination ID	Throughput (Mbps	Delay (µs)	Jitter (µs)	Packets Generated	Packets Received
1	App1_CBR	1	2	0.000000	0.000000	0.000000	94179	0

Figure 4-60: *Application Metrics window*

Discussion

From the results, it is evident that there is no data transmission since wireless node-2 is outside the range of wireless node-1. The range-based parameter is set to 50 meters, whereas wireless node-2 is placed 80 meters away from wireless node-1.

4.9.6 Case 3: Range Based Pathloss with Node Mobility.

The following network diagram illustrates what the NetSim UI displays when you open the example configuration file.

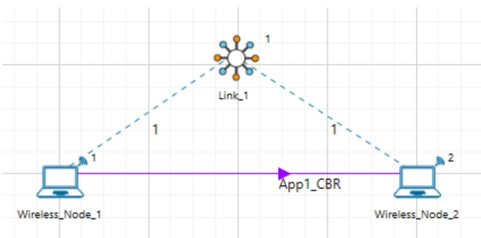


Figure 4-61: *For studying the range based pathloss with ping pong in nature*

Network Settings

1. Set grid length as 400 × 200 from grid setting property panel on the right. This needs to be done before any device is placed on the grid.
2. Drop 2 wireless nodes and 1 Ad hoc link in Grid environment.

3. Device placements of wireless nodes are:

Table 4-19: *Device Placements*

Device	X-Coordinate	Y-Coordinate
Wireless Node-1	100	150
Wireless Node-2	180	150

4. Click on link and expand right-hand side property panel and set Channel Characteristics: Pathloss, Pathloss model to Range based, Range(m)=100 under medium property.
5. Click on Wireless node and expand right-hand side property panel and set Mobility model: No-mobility to Wireless node 1 and Mobility model: File based mobility to wireless node 2 under position property.
6. The file-based mobility pattern specifies that at the 0th second, wireless node 2 will be within range, and at the 5th second, it will move out of range. This cycle of moving in and out of range every 5 seconds repeats continuously for 50-seconds.

#Time(s)	Device ID	X	Y	Z
0	2	190	150	0
5	2	210	150	0
10	2	190	150	0
15	2	210	150	0
20	2	190	150	0
25	2	210	150	0
30	2	190	150	0
35	2	210	150	0
40	2	190	150	0
45	2	210	150	0
50	2	190	150	0

Figure 4-62: *Mobility.csv file*

7. Click on the set traffic tab present in the top ribbon, create a CBR Application with 11Mbps generation rate (Set packet size: 1460, Inter Arrival Time: 1061.81 μs) from wireless node-1 to wireless node-2. Set Transport protocol to UDP and set start time to zero.
8. Clicking on wireless node 1 will open a right-hand side property panel and go to Network layer, enable Static IP Route and configure static route via GUI from Wireless node 1 to Wireless node 2 as shown in below table.

Table 4-20: *Static route configuration for wireless nodes.*

Devices	Network Dest.	Gateway	Subnet Mask	Metrics	Intf. ID
Wireless node 1	192.169.0.3	192.169.0.3	255.255.255.255	1	1

9. In NetSim GUI Application and link throughput vs time plot should be enabled.
10. Run the Simulation for 55 seconds.

4.9.7 Output and Plot

Application Metrics

End-to-end performance of applications running across the network.

Application ID	Application Name	Source ID	Destination ID	Throughput (Mbps	Delay (μs)	Jitter (μs)	Packets Generated	Packets Received
1	App1_CBR	1	2	3.642673	513448.647907	596.083934	51799	17153

Figure 4-63: *Application Metrics window.*

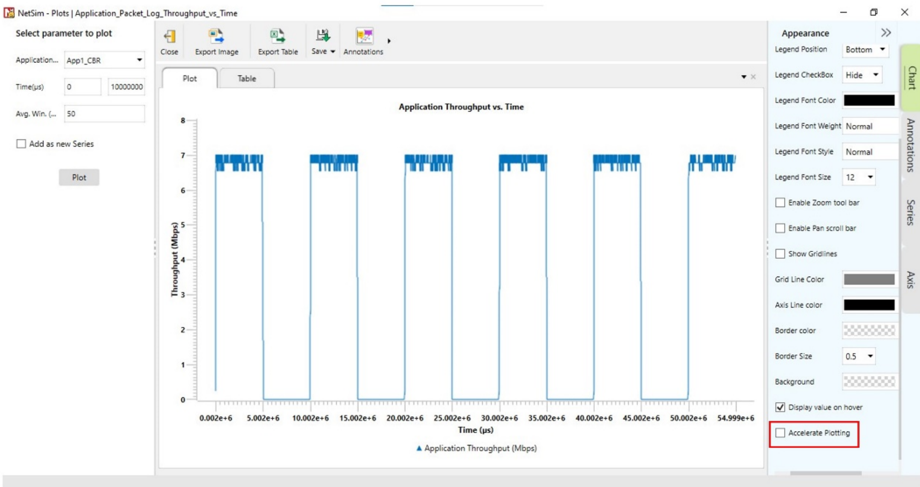


Figure 4-64: *Application throughput vs. Time.*

Discussion

The observed results from the plot indicate that data transmission commences at the 0th second and continues until the 5th second, followed by a pause in transmission until the 10th second. Transmission then resumes from the 15th second and ends at the 20th second. This pattern repeats until the 50th second. This behavior aligns with the mobility pattern defined for wireless node-2, in which it is within a 100-meter range of wireless node-1 for the first 5 seconds, and then moves out of range for the next 5 seconds, and so forth.

4.9.8 Case 4: Range Based Pathloss with Multi-hop Communication.

The following network diagram illustrates what the NetSim UI displays when you open the example configuration file.

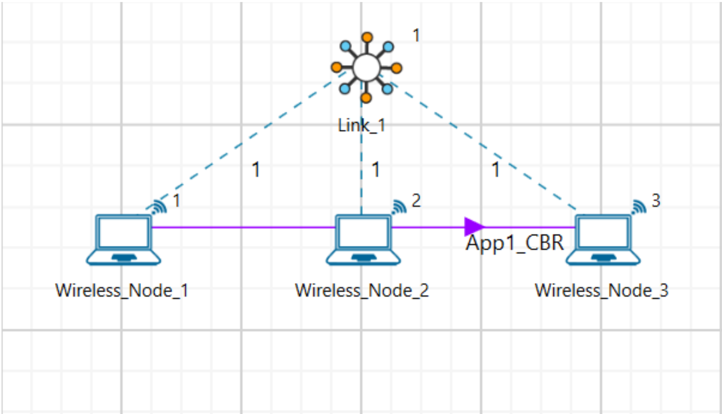


Figure 4-65: *Scenario for studying the range based pathloss model with multihop communication*

Network Settings

1. Set grid length as 400 × 200 from grid setting property panel on the right. This needs to be done before any device is placed on the grid.
2. Drop 3 wireless nodes and 1 Ad hoc link in grid environment.
3. Device placements of wireless nodes are:

Table 4-21: *Device Placements*

Device	X-Coordinate	Y-Coordinate
Wireless Node-1	100	150
Wireless Node-2	140	150
Wireless Node-3	180	150

4. Click on link and expand right-hand side property panel and set Channel characteristics: pathloss, pathloss model to Range based, Range(m)=50 under medium property.
5. Click on wireless node and expand right-hand side property panel and set Mobility model: No-mobility to 3 devices under position property.
6. Configure an application between any two nodes by selecting a CBR application with 11Mbps generation rate (Set packet size: 1460, Inter arrival time: 1061.81 μs) from wireless node-1 to wireless node-3 from the set traffic tab. Set transport protocol to UDP and set start time to zero.
7. Clicking on wireless node 1 and wireless node 2 will open a right-hand side property panel and go to Network layer, enable Static IP Route and configure static route via GUI from wireless node 1 to wireless node 2 and from wireless node 2 to wireless node 3 as shown in below table.

Table 4-22: *Static route configuration for Wireless Node 1 and 2*

Devices	Network Dest.	Gateway	Subnet Mask	Metrics	Intf. ID
Wireless node 1	192.169.0.4	192.169.0.3	255.255.255.255	1	1
Wireless node 2	192.169.0.4	192.169.0.4	255.255.255.255	1	1

8. Enable throughput vs time plot under Application and link performance by clicking on plots/logs tab in right panel.
9. Run the simulation for 100 seconds.

4.9.9 Output and Plot

Application Metrics

End-to-end performance of applications running across the network.

Application ID	Application Name	Source ID	Destination ID	Throughput (Mbps	Delay (µs)	Jitter (µs)	Packets Generated	Packets Received
1	App1_CBR	1	3	3.392222	593950.212111	3691.472762	94179	29043

Figure 4-66: *Application Metrics window.*

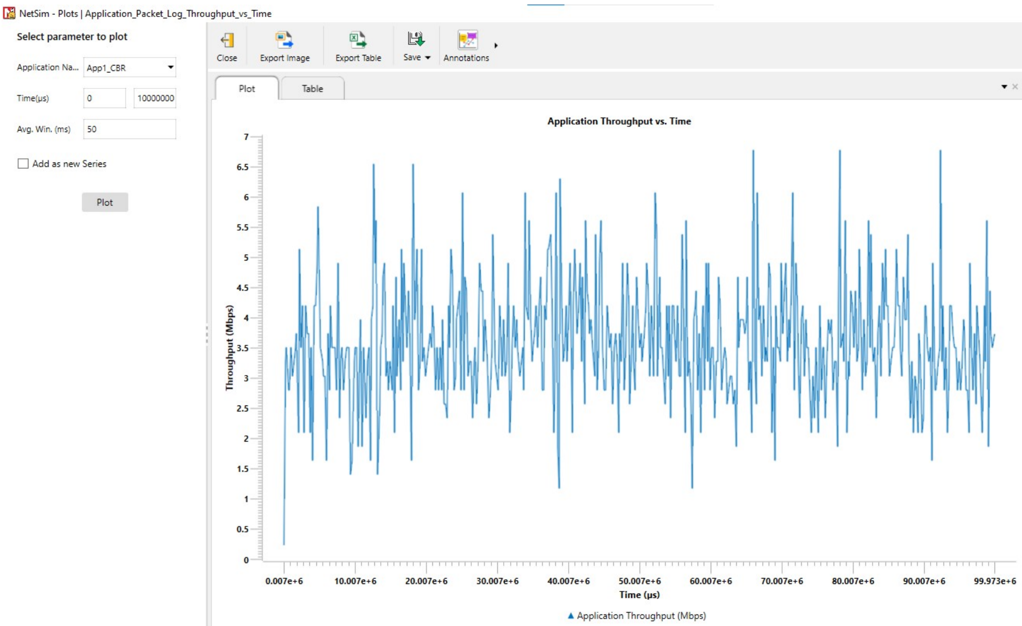


Figure 4-67: *NetSim Plot window.*

In the packet trace, filter packets of type Control Packet Type/APP Name to APP1 CBR. Now you can observe multi-hop communication between node 1 and wireless node 3 via node 2. The configuration involves an application from wireless node 1 to wireless node 3, with a range-based parameter set at 50 meters. The direct distance between wireless node 1 and wireless Node 3 is 80 meters, which exceeds the specified range. However, wireless node 2 is within range of both wireless node 1 and wireless node 3, acting as an intermediate node. Therefore, wireless node 1 utilizes wireless node 2 for data transmission, enabling effective multi-hop communication despite the distance constraints.

A	B	C	D	E	F	G	H	I	J
PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/APP_NAME	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID	APP_LAYER_ARRIVAL_TIME(µS)	TRX_LAYER_ARRIVAL_TIME(µS)
1	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-1	NODE-2	0	0
2	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-1	NODE-2	1061.81	1061.81
3	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-1	NODE-2	2123.62	2123.62
1	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-2	NODE-3	0	0
2	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-2	NODE-3	1061.81	1061.81
3	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-2	NODE-3	2123.62	2123.62
4	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-1	NODE-2	3185.43	3185.43
5	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-1	NODE-2	4247.24	4247.24
6	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-1	NODE-2	5309.05	5309.05
7	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-1	NODE-2	6370.86	6370.86
8	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-1	NODE-2	7432.67	7432.67
9	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-1	NODE-2	8494.48	8494.48
4	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-2	NODE-3	3185.43	3185.43
5	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-2	NODE-3	4247.24	4247.24
6	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-2	NODE-3	5309.05	5309.05
10	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-1	NODE-2	9556.29	9556.29
11	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-1	NODE-2	10618.1	10618.1
12	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-1	NODE-2	11679.91	11679.91
7	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-2	NODE-3	6370.86	6370.86
8	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-2	NODE-3	7432.67	7432.67
13	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-1	NODE-2	12741.72	12741.72
9	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-2	NODE-3	8494.48	8494.48
10	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-2	NODE-3	9556.29	9556.29

Figure 4-68: *Data transmission from WN1 to WN2*

PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/APP_NAME	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID
1	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-1	NODE-2
1	0	CBR	App1_CBR	NODE-1	NODE-3	NODE-2	NODE-3

Figure 4-69: *Filter the Packet Id to 1*

4.9.10 Case 5: Range Based Pathloss with Multi-hop Communication and Node Mobility

The following network diagram illustrates what the NetSim UI displays when you open the example configuration file.

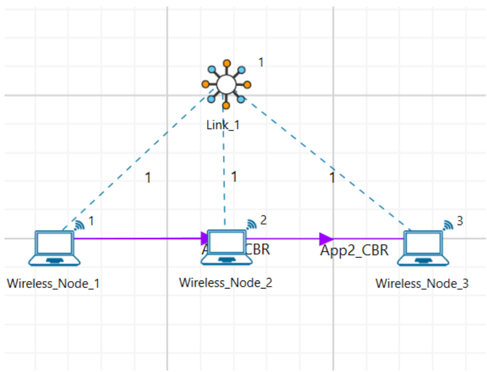


Figure 4-70: *Scenario for studying the range based pathloss model with Multihop and node mobility*

Network Settings

1. Set grid length as 500 × 250 from grid setting property panel on the right. This needs to be done before any device is placed on the grid.
2. Drop 3 wireless nodes and 1 Ad hoc link in Grid environment.
3. Device placements of wireless nodes are:

Table 4-23: *Device Placements*

Device	X-Coordinate	Y-Coordinate
Wireless Node-1	0	200
Wireless Node-2	50	200
Wireless Node-3	100	200

4. Click on link and expand right-hand side property panel and set Channel characteristics: Pathloss, Pathloss model to Range based, Range(m)=50 under medium property.
5. Click on wireless node and expand right-hand side property panel and set mobility model: No-mobility for wireless node 1 and mobility model: File based mobility for wireless node 2 and wireless node 3 under position property.
6. The file-based mobility file specifies the following sequence: At the 0th second, both wireless node 2 (WN2) and wireless Node 3 (WN3) will be out of range. By the 10th second, wireless node 2 will move within range of wireless node 1, while wireless node 3 remains out of range. Starting from the 20th second, wireless node 2 will stay within range, and wireless node 3 will also come into range of wireless node 2. This setup dictates the mobility and connectivity pattern for the nodes throughout the simulation.

#Time(s)	Device ID	X	Y	Z
0	2	51	200	0
0	3	100	200	0
10	2	49	200	0
10	3	100	200	0
20	3	98	200	0

Figure 4-71: *Mobility.csv file*

7. Click on the set traffic tab present in the top ribbon, create CBR application with 11Mbps generation rate (set packet size: 1460, Inter arrival time: 1061.81 μs) from wireless node-1 to wireless node-2 and wireless node-1 to wireless node-3. Set Transport protocol to UDP and set start time to zero.
8. Clicking on wireless node 1 and wireless node 2 will open a right-hand side property panel and go to Network layer, enable static IP route and configure static route via GUI from wireless node 1 to wireless node 2 and from wireless node 2 to wireless node 3 as shown in below table.

Table 4-24: *Static route configuration for wireless nodes 1 and 2*

Devices	Network Dest.	Gateway	Subnet Mask	Metrics	Intf. ID
Wireless node 1	192.169.0.4	192.169.0.3	255.255.255.255	1	1
Wireless node 1	192.169.0.3	192.169.0.3	255.255.255.255	1	1
Wireless node 2	192.169.0.4	192.169.0.4	255.255.255.255	1	1

9. In NetSim GUI Application throughput vs time and Link throughput vs time plots should be enabled.
10. Run the simulation for 60 seconds.

4.9.11 Output and Plot

Application Metrics
End-to-end performance of applications running across the network.

Application ID	Application Name	Source ID	Destination ID	Throughput (Mbps	Delay (µs)	Jitter (µs)	Packets Generated	Packets Received
1	App1_CBR	1	2	1.352155	29989747.250713	6135.679451	56508	6946
2	App2_CBR	1	3	1.343979	36240308.386340	4725.987849	56508	6904

Figure 4-72: *Application Metrics window.*

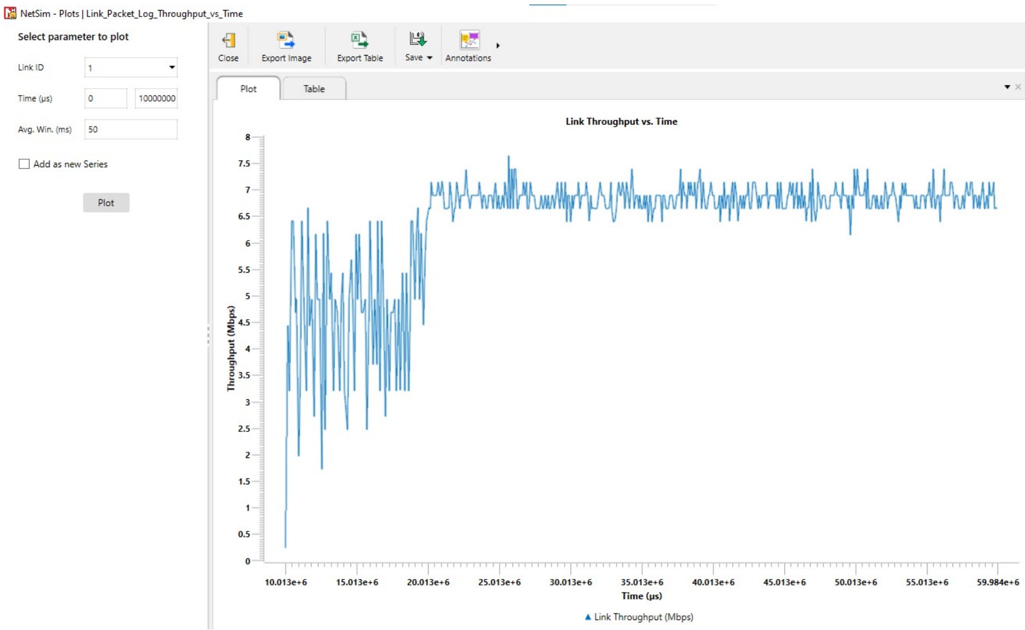


Figure 4-73: *NetSim Link Throughput plot window.*

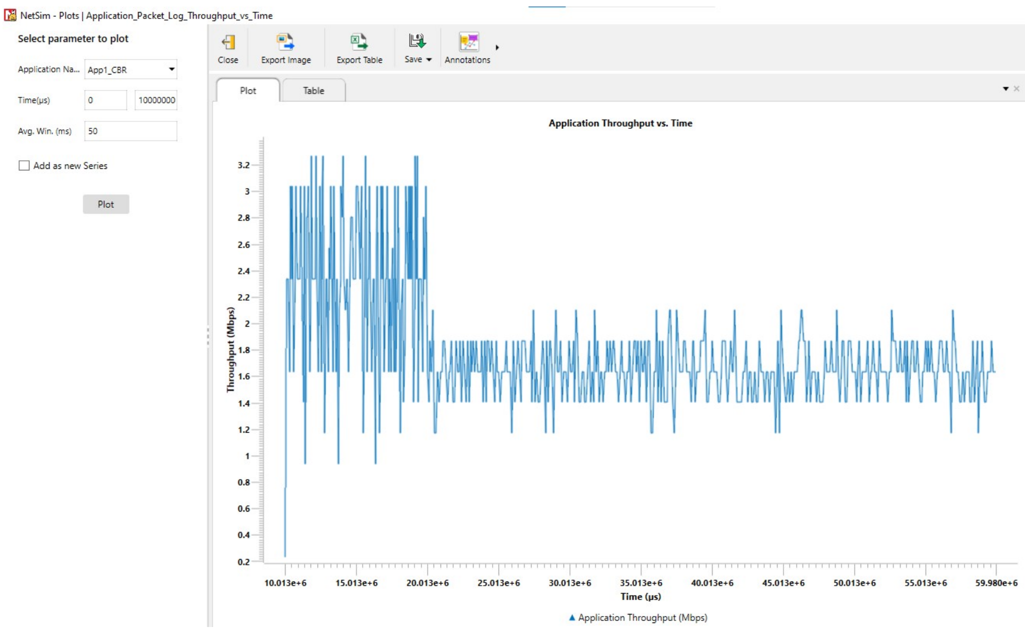


Figure 4-74: *Application 1 Throughput Plot window.*

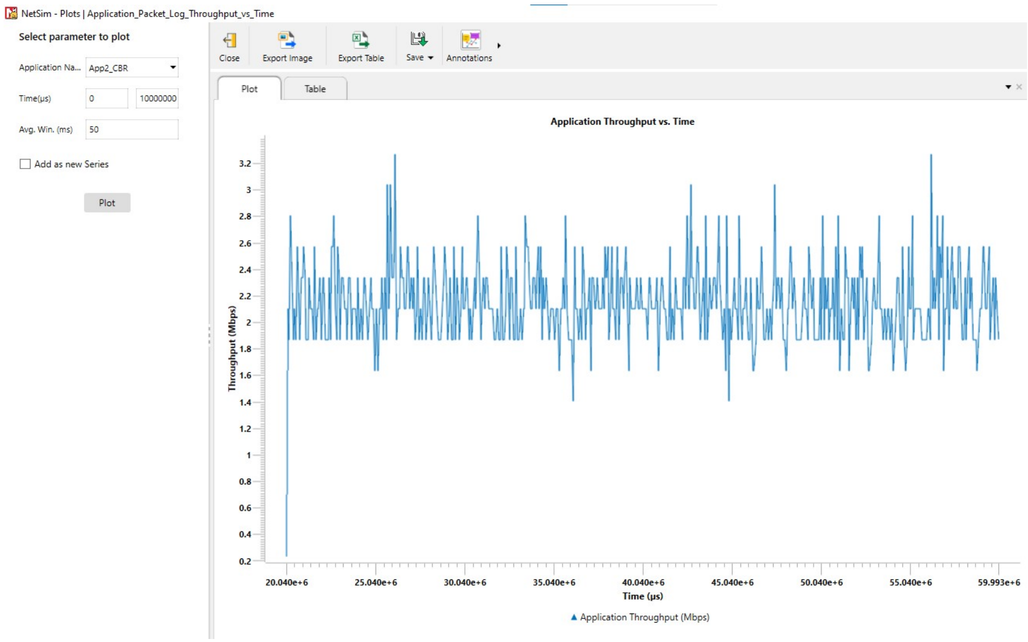


Figure 4-75: *Application 2 Throughput Plot window.*

4.9.12 Case 6: Range Based Pathloss. Nodes within range and beyond range. Broadcast Application

The following network diagram illustrates what the NetSim UI displays when you open the example configuration file.

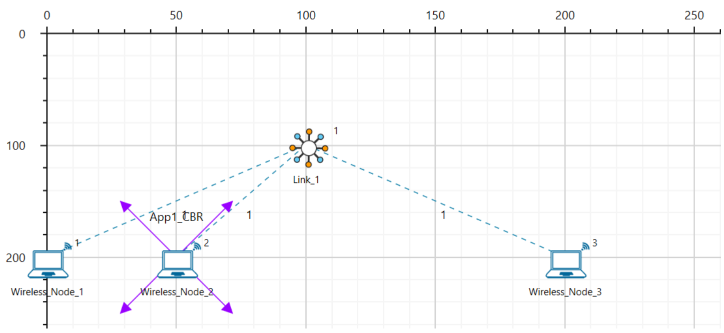


Figure 4-76: *Scenario for studying the range based pathloss within range out-of-range with broadcast application*

Network Settings

1. Set grid length as 600 × 300 from grid setting property panel on the right. This needs to be done before any device is placed on the grid.
2. Drop 3 wireless nodes and 1 ad hoc link in grid environment.
3. Device placements of wireless nodes are:

Table 4-25: *Device Placements*

Device	X-Coordinate	Y-Coordinate
Wireless Node-1	0	200
Wireless Node-2	50	200
Wireless Node-3	200	200

4. Click on link and expand right-hand side property panel and set Channel characteristics: Pathloss, Pathloss model to Range based, range(m)=100 under medium property.
5. Click on wireless node and expand right-hand side property panel and set Mobility model: No-mobility for all the nodes under position property and set Interface-1(wireless), Data link layer, Medium access protocol to DCF.
6. Click on the set traffic tab present in the top ribbon, create broadcast CBR application with 11Mbps generation rate (Set packet size: 1460, Inter arrival time: 1061.81 μs) from wireless node-2. Set Transport protocol to UDP and set start time to zero.
7. Run the simulation for 100 seconds.

Output

PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/APP_NAME	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID
1	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1
2	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1
3	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1
4	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1
5	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1
6	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1
7	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1
8	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1
9	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1
10	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1
11	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1
12	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1
13	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1
14	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1
15	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1
16	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1
17	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1
18	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1
19	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1
20	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1
21	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1
22	0	CBR	App1_CBR	NODE-2	Broadcast-0	NODE-2	NODE-1

Figure 4-77: *Data transmission from WN1 to WN2*

From the packet trace analysis, it is evident that data transmission occurs between wireless node 1 (WN1) and wireless node 2 (WN2), but not between WN2 and WN3. This outcome is due to the broadcast application configured from WN2, with a range-based path loss setting of 100 meters. Since WN1 is within this range of WN2, data transmission is successfully occurring. However, WN3 is positioned outside the 100-meter range, resulting in no data transmission between WN2 and WN3.

Application Metrics

End-to-end performance of applications running across the network.

Application ID	Application Name	Source ID	Destination ID	Throughput (Mbps	Delay (µs)	Jitter (µs)	Packets Generated	Packets Received
1 (Aggregated)	App1_CBR	2	0	0.915011	45842722.246721	0.000000	94179	7834
1	App1_CBR	2	1	0.915011	45842722.246721	11702.520331	94179	7834

Figure 4-78: *Application Metrics window.*

4.9.13 Case 7: Range Based Pathloss. Transmission Failure due to Interference.

The following network diagram illustrates what the NetSim UI displays when you open the example configuration file.

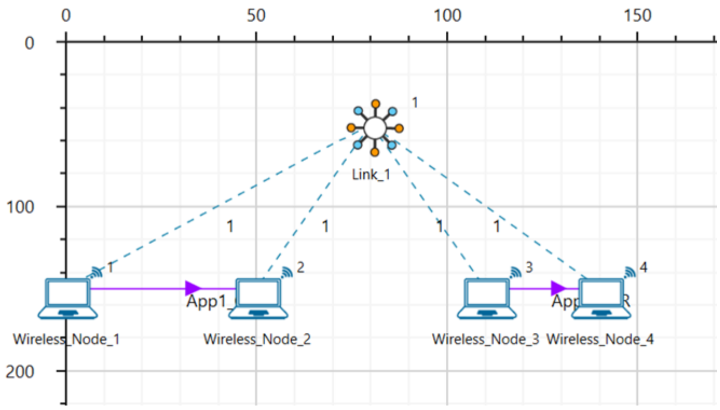


Figure 4-79: *Scenario for studying the range based pathloss Transmission failure due to interference from neighboring transmissions*

Network Settings

1. Set grid length as 400 × 200 from grid setting property panel on the right. This needs to be done before any device is placed on the grid.
2. Drop 4 wireless nodes and 1 Ad hoc link in grid environment.
3. Device placements of wireless nodes are:

Table 4-26: *Device Placements*

Device	X-Coordinate	Y-Coordinate
Wireless Node-1	0	150
Wireless Node-2	50	150
Wireless Node-3	110	150
Wireless Node-4	140	150

4. Click on link and expand right-hand side property panel and set Channel Characteristics: Pathloss, Pathloss model to Range Based, Range(m)=100.
5. Click on Wireless node and expand right-hand side property panel and set Mobility Model: No-Mobility for all the nodes under position property and set Interface-(Wireless), Data Link Layer, Medium access protocol to DCF.
6. Click on the set traffic tab present in the top ribbon, create CBR application with 11Mbps generation rate (Set Packet size: 1460, Inter Arrival Time: 1061.81 μs) from Wireless Node-1 to Wireless Node-2 and Wireless Node-3 to Wireless Node-4. Set Transport Protocol to UDP and Set start time to zero.
7. Run the Simulation for 100 seconds.

Output

In this scenario we have traffic from WN1 to WN2 and from WN3 to WN4. Note however that WN2 is within the range of WN3. In this scenario there is no successful data transmission between WN1 to WN 2. This is because WN2 is within the range of WN 3 which is transmitting to WN4. Packets sent from WN1 cannot be successfully received (decoded) at WN2 due to the interference of the WN3 to WN4 transmission.

Application Metrics

End-to-end performance of applications running across the network.

Application ID	Application Name	Source ID	Destination ID	Throughput (Mbps	Delay (µs)	Jitter (µs)	Packets Generated	Packets Received
1	App1_CBR	1	2	0.000000	0.000000	0.000000	94179	0
2	App2_CBR	3	4	5.919307	23101726.379051	911.309361	94179	50679

Figure 4-80: *Application Metrics. We see that the first application has NIL throughput while the second application sees throughput.*

4.9.14 Case 8: Range Based Pathloss. Carrier sense (CS) blocking due to neighboring transmissions.

The following network diagram illustrates what the NetSim UI displays when you open the example configuration file.

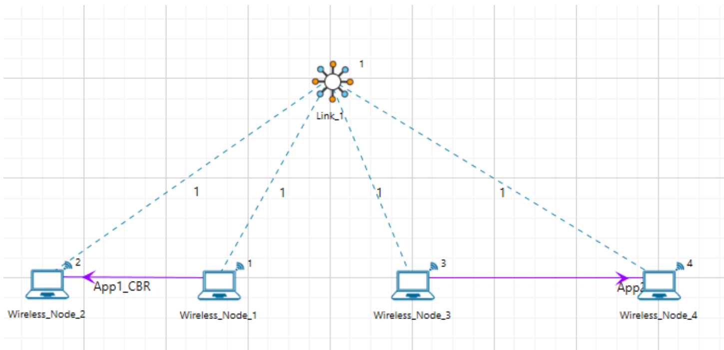


Figure 4-81: *Scenario for studying the range based pathloss Carrier sense (CS) Blocking due to neighboring transmissions.*

Network Settings

1. Set grid length as 400 × 200 from grid setting property panel on the right. This needs to be done before any device is placed on the grid.
2. Drop 4 wireless nodes and 1 Ad hoc link in Grid environment.
3. Device placements of wireless nodes are:

Table 4-27: *Device Placements*

Device	X-Coordinate	Y-Coordinate
Wireless Node-1	50	150
Wireless Node-2	0	150
Wireless Node-3	100	150
Wireless Node-4	160	150

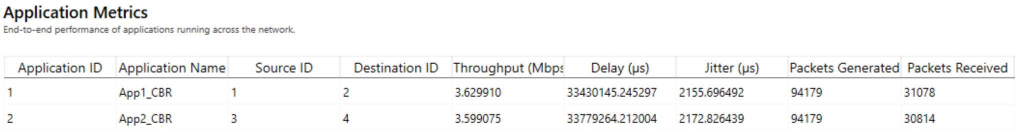
4. Click on link and expand right-hand side property panel and set Channel Characteristics: Pathloss, Pathloss model to Range Based, Range(m)=100.
5. Click on Wireless node and expand right-hand side property panel and set Mobility Model: No-Mobility for all the nodes under position property and set Interface-(Wireless), Data Link Layer, Medium access protocol to DCF.
6. Click on the set traffic tab present in the top ribbon, create CBR Application with 11Mbps generation rate (Set Packet size: 1460, Inter Arrival Time: 1061.81 μs) from Wireless Node-1 to Wireless Node-2 and Wireless Node-3 to Wireless Node-4. Set Transport Protocol to UDP and Set start time to zero.

7. Run the Simulation for 100 seconds.

Output

We observe that Wireless Node 1 (WN1) is within the range of Wireless Node 2 (WN2) and Wireless Node 3 (WN3), and WN3 is also within range of Wireless Node 4 (WN4). We have configured one application from WN1 to WN2 and another from WN3 to WN4.

In this scenario, WN1 is within the carrier sense range of both WN3 and WN4. Consequently, when WN3 transmits data to WN4, WN1 will delay its transmission due to carrier sense blocking, as it detects the active transmission nearby. Similarly, when WN1 is transmitting data to WN2, WN3 will wait before transmitting to WN4, as it is within the carrier sense range of WN1.


Application Metrics
End-to-end performance of applications running across the network.

Application ID	Application Name	Source ID	Destination ID	Throughput (Mbps	Delay (μs)	Jitter (μs)	Packets Generated	Packets Received
1	App1_CBR	1	2	3.629910	33430145.245297	2155.696492	94179	31078
2	App2_CBR	3	4	3.599075	33779264.212004	2172.826439	94179	30814

Figure 4-82: *Application Metrics window*

On the other hand, with only WN1-WN2 transmission the obtained throughput is 5.92 Mbps and with only WN3-WN4 transmission the throughput is 5.91 Mbps. We see that when both transmissions are occurring simultaneously the individual throughputs drop to 3.62 Mbps and 3.59 Mbps due to carrier sense blocking.

4.10 OLSRv2 Multi-cluster MANET

4.10.1 Scenario Overview

The OLSRv2 Multi-cluster MANET example is a 15-node pure wireless MANET simulation that demonstrates the key features of the Optimized Link State Routing Protocol Version 2 (OLSRv2), as implemented in NetSim Pro v15.0.

The network is arranged as three clusters connected by dedicated relay nodes. There is no wired infrastructure; every node is a wireless ad-hoc peer. The scenario uses a deterministic three-phase design: the topology is stable during each phase, with a single, precisely controlled node movement triggering each phase transition. This eliminates randomness and makes every protocol event predictable and verifiable.

Propagation Model – Range-Based Pathloss

The scenario uses range-based pathloss with a fixed range of 250 m. This is a deterministic, binary propagation model:

- Two nodes within 250 m of each other can communicate (link exists, perfect quality).
- Two nodes farther than 250 m apart cannot communicate (no link).

Configured via the wireless link's <MEDIUM PROPERTY> element:

```
PATHLOSS MODEL="RANGE BASED" RANGE="250"
```

The range applies globally to all nodes on the same wireless link. Combined with file-based mobility, the topology at every instant is fully determined by the node coordinates.

Mobility Model – File-Based

Instead of random mobility, this scenario uses file-based mobility (`FILE BASED MOBILITY`). A CSV file specifies the exact position of each moving node at exact times. Positions change instantaneously at the specified time with no interpolation and no randomness. Only Node 5 moves. All other 14 nodes are static. The mobility file contains three entries that define the three phases.

What This Example Demonstrates

- Flooding MPR and Routing MPR selection under varying willingness values.
- The catastrophic effect of `WILL_NEVER` when the willing bridge fails.
- The effect of TC hop limit truncation.
- Triggered TC messages and route recomputation after a deterministic topology change.
- Energy consumption differences across node roles.
- The full NHDP neighbour discovery lifecycle.
- Clean before, during, and after metrics for each phase.

Simulation Configuration

Use the following simulation configuration for the OLSRv2 Multi-cluster MANET example:

1. 15 wireless nodes in a MANET scenario with OLSRv2 as the routing protocol.
2. Wireless link properties:
    - Standard: 802.11g
    - Pathloss model: Range Based
    - Range: 250 m
    - Channel characteristics: Pathloss only
    - Propagation medium: Air
3. All 15 nodes placed at the Phase 1 coordinates shown below.
4. Willingness per node:
    - Nodes 7 and 13: `WILL_FLOODING = WILL_ROUTING = 15`
    - Node 6: `WILL_FLOODING = WILL_ROUTING = 0`
    - All others: default value 7
5. `TC HOP LIMIT = 4` on Node 5 only.
6. Mobility file: `ConfigSupport\mobility.csv`.
7. Node 5 mobility: `FILE BASED MOBILITY`. All other nodes: `NO MOBILITY`.
8. Four CBR/UDP flows with start time $t = 20$ s.
9. Link quality disabled.
10. Simulation time: 300 s.

4.10.2 Network Topology – Phase 1 (Baseline)

Parameter Configuration

Table 4-28: *Configuration Parameters for the Scenario*

Parameter	Value	Rationale
Hello Interval	2 s	Default
Hello Min Interval	0.5 s	Default (HELLO INTERVAL / 4)
HP Maxjitter	0.5 s	Default (HELLO INTERVAL / 4)
TC Interval	5 s	Default
TC Min Interval	1.25 s	Default (TC INTERVAL / 4)
TP Maxjitter	0.5 s	Same as HP Maxjitter
TC Hop Limit	255 (Node 5: 4)	Demonstrates hop-limit truncation
T hold time	15 s	Default (3 × TC INTERVAL)
A hold time	15 s	Default
Link Quality	Disabled	Default; not useful with range-based pathloss
Pathloss Model	Range-Based	Deterministic binary model
Range	250 m	Produces the designed topology
Wireless Standard	802.11g	Typical MANET radio
Mobility (Node 5)	File-Based	See the mobility listing below
Mobility (all others)	No Mobility	Static nodes
Simulation Time	300 s	Three phases with ample measurement windows

Topology Diagram

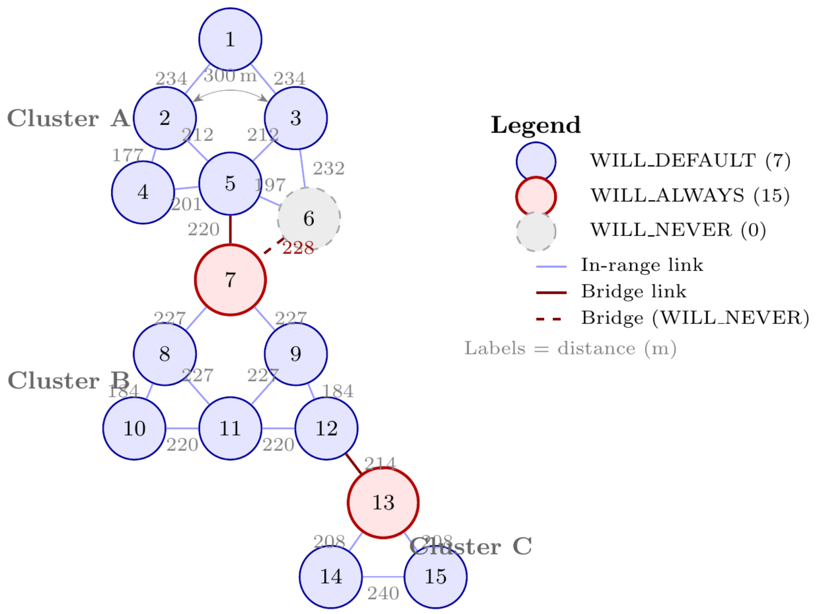


Figure 4-83: *Phase 1 topology (baseline). 22 links. All links are within the 250 m range. The dashed red link 6–7 exists physically but Node 6's `WILL_NEVER` prevents relaying.*

Node Placement

Table 4-29: *Node Positions (Phase 1), Roles, and Configuration*

Node	X	Y	Role	Willingness
1	300	1280	Cluster A hub	DEFAULT (7)
2	150	1100	Cluster A core	DEFAULT (7)
3	450	1100	Cluster A core	DEFAULT (7)
4	100	930	Cluster A edge	DEFAULT (7)
5	300	950	Cluster A / bridge to B	DEFAULT (7)
6	480	870	Cluster A / alt. bridge	NEVER (0)
7	300	730	Relay A–B	ALWAYS (15)
8	150	560	Cluster B core	DEFAULT (7)
9	450	560	Cluster B core	DEFAULT (7)
10	80	390	Cluster B edge	DEFAULT (7)
11	300	390	Cluster B edge	DEFAULT (7)
12	520	390	Cluster B / bridge to C	DEFAULT (7)
13	650	220	Relay B–C	ALWAYS (15)
14	530	50	Cluster C	DEFAULT (7)
15	770	50	Cluster C	DEFAULT (7)

Table 4-30: *Phase 1 Links (22 Total). All Distances Computed from the Node Coordinates*

Region	Link	Distance (m)	Note
Cluster A	1–2	234	
Cluster A	1–3	234	
Cluster A	2–4	177	
Cluster A	2–5	212	
Cluster A	3–5	212	
Cluster A	3–6	232	
Cluster A	4–5	201	
Cluster A	5–6	197	
Bridge A–B	5–7	220	Primary bridge
Bridge A–B	6–7	228	`WILL_NEVER`; cannot relay
Cluster B	7–8	227	
Cluster B	7–9	227	
Cluster B	8–10	184	
Cluster B	8–11	227	
Cluster B	9–11	227	
Cluster B	9–12	184	
Cluster B	10–11	220	
Cluster B	11–12	220	
Bridge B–C	12–13	214	Sole bridge
Cluster C	13–14	208	
Cluster C	13–15	208	
Cluster C	14–15	240	

Adjacency List

Table 4-31: *Key Non-Links Greater Than 250 m*

Pair	Distance (m)	Why It Matters
2–3	300	Forces Node 1 to need both 2 and 3 as MPRs
1–5	330	Node 1 cannot reach the bridge directly
4–7	283	No shortcut from Cluster A edge to relay
6–8	453	`WILL_NEVER` node isolated from Cluster B
8–9	300	Cluster B cores are not directly connected
7–11	340	Relay cannot skip the Cluster B core
9–13	394	No shortcut from Cluster B to relay C

4.10.3 Simulation Phases

The simulation is divided into three phases, each with a stable topology. Transitions between phases are triggered by a single, instantaneous position change of Node 5.

Table 4-32: *Simulation Phases*

Phase	Time Window	Node 5 Position	Topology State
1 – Baseline	$t = 0$ to $t = 50$ s	$(300, 950)$	Full connectivity (22 links)
2 – Bridge Break	$t = 50$ to $t = 150$ s	$(300, 1000)$	A–B disconnected (21 links)
3 – Recovery	$t = 150$ to $t = 300$ s	$(300, 950)$	Full connectivity restored (22 links)

Mobility File

The entire mobility specification is a three-line CSV file. Only Node 5 has entries; all other nodes use `NO MOBILITY`.

```
#Time(s),Device ID,X,Y,Z
0,5,300,950,0
50,5,300,1000,0
150,5,300,950,0
```

Node 5 is configured with:

```
<MOBILITY MODEL="FILE BASED MOBILITY" OPEN MOBILITY FILE="ConfigSupport\mobility.csv" />
```

Phase 1 – Baseline ($t = 0$ to $50\,s$)

Topology: the full 22-link network. Node 5 at $(300, 950)$ is within 220 m of Node 7, so the primary A–B bridge is active.

Protocol activity:

1. $t = 0$ to 16 s: NHDP convergence. HELLO messages propagate hop by hop and links transition `PENDING` → `HEARD` → `SYMMETRIC`. With `HELLO INTERVAL = 2 s` and a 7-hop diameter, full symmetric neighbour discovery completes by approximately 16 s.

2. $t = 5$ to 20 s: TC propagation. The first TC messages are generated at approximately 5 s. They flood via MPRs across the 7-hop chain, and routing tables populate progressively.
3. $t = 20$ s: all application flows start. The network is in steady state.
4. $t = 20$ to 50 s: baseline measurement window (30 s).

Steady-state routing paths:

Table 4-33: *Steady-State Routing Paths in Phase 1*

Flow	Path	Hops	Status
F1 (10→15)	10→11→12→13→15	4	Active
F2 (4→11)	4→5→7→8→11 (or via 9)	4	Active
F3 (14→1)	14→13→12→9→7→5→2→1	7	Active
F4 (3→8)	3→5→7→8	3	Active

Phase 2 – Bridge Break ($t = 50$ to $150\,s$)

At $t = 50$ s, Node 5 moves instantaneously from $(300, 950)$ to $(300, 1000)$, a shift of 50 m north.

Table 4-34: *Link Impact During the Bridge Break*

Link	Before (m)	After (m)	Status	Comment
5–7	220	270	BROKEN	Exceeds 250 m
5–2	212	180	OK	Closer
5–3	212	180	OK	Closer
5–4	201	212	OK	Slightly farther
5–6	197	222	OK	Slightly farther
1–5	330	280	Still out	Still greater than 250 m

The `WILL_NEVER` Trap

After the bridge break, the only physical link between Cluster A and Node 7 is 6↔7 (228 m, still within range). But Node 6 has `WILL_NEVER = 0`:

- Node 6 is not an MPR, so it does not relay TC messages.
- Node 6 does not forward data packets.
- The link 6–7 is physically present but useless for transit.

As a result, Clusters A and B+C become disconnected for all transit traffic. This is the most dramatic demonstration of `WILL_NEVER`: a single willing bridge fails, and the physically available alternative cannot compensate.

Protocol Events at $t = 50$ s

1. Node 5 and Node 7 detect link loss via NHDP (HELLO timeout, approximately 6 s = `H HOLD TIME`).
2. Link status transitions `SYMMETRIC` → `HEARD` → `LOST`.
3. Node 7 increments its ANSN (Advertised Neighbour Sequence Number) and generates a triggered TC message.

4. Node 5 also generates a triggered TC because it lost Node 7 as a neighbour.
5. The triggered TCs propagate via MPRs: Node 7's TC reaches Clusters B and C, while Node 5's TC reaches Cluster A. Neither TC crosses the broken bridge.
6. Every node that receives the TC recomputes its routing table using Dijkstra.
7. Routes between Clusters A and B/C are removed because no valid next hop exists.

Table 4-35: *Detection Timeline for the Bridge Break*

Time	Event
$t = 50$ s	Node 5 moves; link 5–7 physically breaks
$t \approx 52$ s	Next HELLO from Node 5 is not heard by Node 7, and vice versa
$t \approx 56$ s	L_SYM time expires on both ends, moving to `HEARD`
$t \approx 56$ s	`H HOLD TIME` (6 s) expires, moving to `LOST`
$t \approx 56$ s	Triggered TC messages from Nodes 5 and 7
$t \approx 58$ to 65 s	TC propagation and route settling complete across the remaining topology
$t \approx 58$ to 65 s	Routing tables update and flows F2, F3, and F4 begin dropping packets after reconvergence

Table 4-36: *Flow Status During Phase 2*

Flow	Status	Reason
F1 (10→15)	Active	Path 10→11→12→13→15 remains within B+C
F2 (4→11)	BROKEN	Requires the A→B bridge; no willing path exists
F3 (14→1)	BROKEN	Requires the B→A bridge; no willing path exists
F4 (3→8)	BROKEN	Requires A→B bridging; Node 6 cannot relay

Phase 3 – Recovery ($t = 150$ to $300\,s$)

At $t = 150$ s, Node 5 returns instantaneously to $(300, 950)$ and link 5–7 reforms.

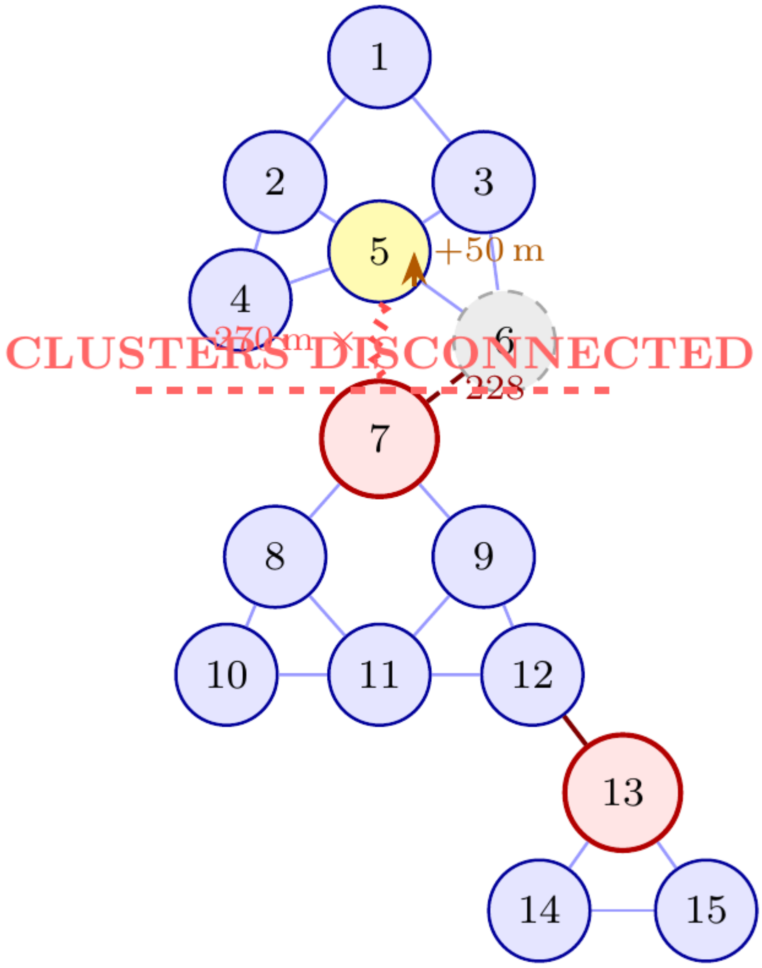


Figure 4-84: *Phase 2 topology. Node 5 moves 50 m north (highlighted yellow) and link 5–7 breaks because 270 m exceeds the 250 m range. The only remaining A–B connection is 6–7, but Node 6's `WILL_NEVER` blocks all relaying.*

Protocol Events at $t = 150$ s

1. Node 5's HELLO reaches Node 7 again. The link transitions `LOST` → `HEARD` → `SYMMETRIC`, requiring two HELLO exchanges and approximately 4 s.
2. Both nodes generate triggered TC messages announcing the restored neighbour.
3. Triggered TCs propagate via MPRs across both sides of the network.
4. Routing tables are recomputed with the restored bridge, and routes between Clusters A and B/C reappear after the protocol settles.
5. All four flows recover.

Table 4-37: *Recovery Timeline*

Time	Event
$t = 150$ s	Node 5 moves back; link 5–7 becomes physically available
$t \approx 152$ s	Node 5's HELLO is heard by Node 7, moving to `HEARD`
$t \approx 154$ s	Symmetric confirmation through the second HELLO, moving to `SYMMETRIC`
$t \approx 154$ s	Triggered TC messages from Nodes 5 and 7
$t \approx 156$ to 165 s	TC propagation and route settling continue
$t \approx 156$ to 165 s	Routing tables restore and flows F2, F3, and F4 resume delivery

Measurement window: $t = 165$ to 300 s (135 s of restored steady state).

Expected outcome: Phase 3 metrics should closely match Phase 1 metrics for all four flows, confirming that the protocol fully recovers from the disruption.

4.10.4 Features Exercised

MPR Selection – Flooding and Routing

Node 1's MPR Selection (all phases). Node 1's one-hop neighbours are {2, 3}. The two-hop set is:

- via Node 2: {4, 5}
- via Node 3: {5, 6}

The unique two-hop set is {4, 5, 6}. Node 2 covers {4, 5}, and Node 3 covers {5, 6}. Neither alone covers all three, so both are selected as MPRs.

Node 5's MPR Selection (Phases 1 and 3). The one-hop neighbours are {2, 3, 4, 6, 7}. The two-hop set is {1, 8, 9}. Node 2 or Node 3 covers {1}, while Node 7 covers {8, 9} and has `WILL_ALWAYS`, guaranteeing selection. Node 6 provides no unique two-hop coverage and has `WILL_NEVER`, so it is never selected.

Node 5's MPR Selection (Phase 2). Node 5 loses Node 7 as a neighbour. The new one-hop set is {2, 3, 4, 6}. The new two-hop set is {1, 7}, with Node 7 learned as a two-hop neighbour via Node 6. The MPR set shrinks relative to Phase 1.

Flooding vs. Routing MPRs. OLSRv2 maintains separate flooding and routing MPR sets (RFC 7181 Sections 18.1 and 18.4). Both are independently configurable via `WILL_FLOODING` and `WILL_ROUTING`.

Willingness Variation and the `WILL_NEVER` Trap

`WILL_ALWAYS (15)` is configured on Nodes 7 and 13, guaranteeing MPR selection. `WILL_NEVER (0)` is configured on Node 6, so it never relays. In Phase 1 this is merely observable; in Phase 2 it becomes critical because the only physical A–B link is 6–7, but `WILL_NEVER` renders it useless for transit, disconnecting the clusters. All other nodes use `WILL_DEFAULT (7)`.

TC Hop Limit Truncation

Observe the effect of `TC HOP LIMIT` for Node 5 by comparing these two cases:

- `TC HOP LIMIT = 255`: Node 5's TC propagates normally through the connected topology.
- `TC HOP LIMIT = 4`: Node 5's TC is forwarded only up to the fourth hop. The node at hop 4 may receive the TC, but it does not retransmit it further.

Triggered TC Messages

Periodic TCs are generated every 5 s. However, topology changes trigger immediate TC messages, subject to `TP MAXJITTER = 0.5 s`. This scenario produces two triggered-TC bursts:

1. Around $t \approx 56$ to 65 s, after the link 5–7 loss.
2. Around $t \approx 154$ to 165 s, after the link 5–7 restoration.

NHDP Neighbour Discovery Lifecycle

Neighbour discovery is observable in three contexts:

1. Initial convergence ($t = 0$ to 16 s): all links transition `PENDING` → `HEARD` → `SYMMETRIC`.
2. Link loss (around $t \approx 52$ to 65 s): link 5–7 transitions `SYMMETRIC` → `HEARD` → `LOST`.
3. Link recovery (around $t \approx 150$ to 165 s): link 5–7 transitions `LOST` → `HEARD` → `SYMMETRIC`.

Energy Consumption by Role

All nodes use the default NetSim energy model (TX: 316.7 mA, RX: 261.1 mA, Idle: 227 mA, Voltage: 3.6 V).

Phase-dependent expected results:

- Node 7 (`WILL_ALWAYS` relay) has the highest TX energy in Phases 1 and 3 because it relays all cross-cluster traffic.
- In Phase 2, Node 7's TX energy drops because it no longer relays A→B traffic; only B→C traffic remains.
- Node 6 (`WILL_NEVER`) has the lowest TX energy in all phases.
- Node 13 remains consistently active as the B–C bridge, unaffected by Node 5's movement.

4.10.5 Traffic Flows

Four concurrent CBR/UDP flows start at $t = 20$ s and run for the remainder of the simulation.

Table 4-38: *Application Traffic Flows*

Flow	Src	Dst	Type	Packet Size	Rate	Purpose
F1	10	15	CBR/UDP	512 B	10 pkt/s	Entirely within B+C (4 hops); unaffected by the bridge break and serves as a control flow
F2	4	11	CBR/UDP	512 B	10 pkt/s	Crosses A→B via Node 7; breaks in Phase 2
F3	14	1	CBR/UDP	512 B	5 pkt/s	Longest path (7 hops); breaks in Phase 2
F4	3	8	CBR/UDP	256 B	20 pkt/s	`WILL_NEVER` bypass demonstration (3 hops); breaks in Phase 2

Per-Phase Flow Behaviour

F1 remains active across all three phases because its path 10→11→12→13→15 never crosses the A–B bridge. F2, F3, and F4 break during Phase 2 and recover in Phase 3 after reconvergence. The windows $t = 50$ to 65 s and $t = 150$ to 165 s are transient intervals rather than steady-state measurement periods.

4.10.6 Simulation Results – Phase by Phase

Phase 1 Observations (Baseline, $t = 20$ to $50\,s$)

Observation	Where to Look	Expected Result
MPR tables	OLSR link metrics log	Node 1 MPRs = {2, 3}. Node 5 MPRs include Node 7 (`WILL_ALWAYS`). Node 6 never appears as an MPR for any node.
WILL_NEVER effect	Routing tables	Node 6 is reachable as a destination but never used as a next hop. Flow F4 uses 3→5→7→8, not 3→6→7→8.
TC hop limit	Packet trace	Node 5's TCs are limited to 4 hops. The node at hop 4 may receive the TC but does not forward it further, so Nodes 14 and 15 are not reached directly. Other nodes' TCs propagate Node 5's information farther.
Full convergence	Routing table timestamps	All 15 nodes have complete routing tables by approximately $t = 16$ to 20 s.
All flows active	Application metrics	F1 remains active on its 4-hop path. F2–F4 are also active in the baseline phase on their respective paths.
Jitter	Packet trace	HELLO and TC transmission times vary by up to 0.5 s and 0.5 s, respectively, from the periodic schedule.

Phase 2 Observations (Bridge Break, $t = 50$ to $150\,s$)

Observation	Where to Look	Expected Result
Link 5–7 loss	NHDP logs	`SYMMETRIC` → `HEARD` → `LOST` on both Node 5 and Node 7 at approximately $t = 56$ s.
Triggered TC burst	Packet trace	Non-periodic TCs from Nodes 5 and 7 at approximately $t = 56$ s, clearly distinguishable from the 5 s periodic cadence.
ANSN increment	TC message headers	Nodes 5 and 7 increment ANSN in the triggered TCs.
MPR table change	OLSR link metrics log	Node 5's MPR set shrinks because it loses Node 7. Node 7's MPR set shrinks because it loses Node 5.
Route removal	Routing tables	All Cluster A nodes lose routes to Cluster B/C nodes and vice versa. Intra-cluster routes remain intact on both sides.
F1 unaffected	Application metrics	F1 remains active throughout because its path is entirely within B+C.
F2/F3/F4 broken	Application metrics	Delivery drops after approximately $t = 58$ to 65 s once reconvergence completes.
Node 7 energy drop	Energy logs	Node 7's TX energy rate decreases in Phase 2 because it no longer relays A→B data or TCs from Cluster A.

WILL_NEVER trap	Routing tables (Node 6)	Node 6 still has a `SYMMETRIC` link to Node 7, but its routing table shows no routes to Cluster B/C because Node 7's TCs are not relayed back via Node 6. Even if routes were present, Node 6 would still not forward.

Phase 3 Observations (Recovery, $t = 150$ to $300\,s$)

Observation	Where to Look	Expected Result
Link 5–7 recovery	NHDP logs	`LOST` → `HEARD` → `SYMMETRIC` on both ends at approximately $t = 154$ s.
Triggered TC burst	Packet trace	Second burst of non-periodic TCs from Nodes 5 and 7.
Route restoration	Routing tables	Cross-cluster routes reappear network-wide after recovery, typically around $t =$ 156 to 165 s depending on settling time. Paths then match Phase 1 again.
F2/F3/F4 resume	Application metrics	Traffic resumes only after reconvergence. The interval around $t = 150$ to 165 s shows partial restoration while NHDP re-establishes the link and routing tables settle.
Metrics match Phase 1	All logs	Phase 3 steady-state metrics should closely match Phase 1, confirming full protocol recovery. Persistent differences indicate a convergence defect.

4.10.7 Running the Example in NetSim

Open the OLSRv2 Multi-cluster MANET example in NetSim Pro v15.0. The example is pre-configured with all node positions, willingness values, mobility, traffic flows, and protocol settings described in this section.

Observing Simulation Results and TC Hop Limit Effects

After running the simulation, the following outputs can be observed:

- OLSR link metrics log: displays MPR tables for each phase.
- Packet trace: observe the difference between the default hop limit (255) and Node 5 configured with hop limit 4, along with triggered TC bursts at $t \approx 56$ s and $t \approx 154$ s.
- Routing table snapshots: tables at different time instances, such as $t = 40$ s, $t = 100$ s, and $t = 200$ s, illustrate routing changes across phases.
- Application metrics: show delivery ratio and delay for each flow across phases.
- Energy logs: highlight variations in transmission energy across nodes, such as Node 7 versus Node 6.

TC Hop Limit

The TC Hop Limit controls how far a TC (Topology Control) message propagates in the network.

Steps to Verify the Effect

1. Run the simulation and open the Packet Trace window.
2. Apply the following filters:
   - Packet Type = `TC_MESSAGE`
   - Source Node = 5
3. Identify the TC messages generated by Node 5.
4. Track a selected TC packet as it propagates through neighbouring nodes across the network.

Expected Observations

- **For Node 5 (TC Hop Limit = 4):**
  - The TC message is forwarded only up to four hops from the source node.
  - When the hop count reaches 4, the packet is received by the node but is not forwarded further.
  - Nodes located beyond four hops do not receive this TC message directly.
- **For Other Nodes (Default TC Hop Limit = 255):**
  - TC messages propagate throughout the entire network without early termination.

Verification Method

Compare TC packets generated by Node 5 with TC packets generated by other nodes in the network. Only the TC messages originating from Node 5 will demonstrate early truncation due to the reduced hop limit, confirming the effect of the configured TC Hop Limit.

4.10.8 Conclusion

This example provides a fully deterministic evaluation of OLSRv2. Range-based pathloss and file-based mobility ensure that every topology change is precisely controlled and every protocol event is reproducible.

The three-phase design produces a clean before, during, and after comparison:

- Phase 1 establishes the baseline: MPR selection, TC propagation, multi-hop routing, and energy consumption under full connectivity.
- Phase 2 shows the protocol's response to a controlled disruption: triggered TC generation, route removal, ANSN updates, and the catastrophic impact of `WILL_NEVER` when the sole willing bridge fails.
- Phase 3 confirms complete recovery: link re-establishment, route restoration, and metric convergence back to baseline.

The control flow F1, which is unaffected by the bridge break, confirms that the disruption is localised to cross-cluster paths.

5 References

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6 Latest FAQs

Up-to-date FAQs on NetSim's MANET library are available at

https://tetcos.freshdesk.com/support/solutions/folders/14000110331