NetSim®

Accelerate Network R & D

Internet of Things (IOT)

and

Wireless Sensor Networks (WSN)

A Network Simulation & Emulation Software

By

TETCOS LLP

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1 Introduction

Internet of Things (IoT) is an ecosystem of devices that connect to and communicate via the internet. A typical IOT deployment consists of

- Embedded devices / sensors.
- Communication over an IP network (between the devices and to/from cloud servers).
- Cloud services, Big Data, Analytics / Machine learning on the cloud.

NetSim can be used to simulate the communication network. The sensors used in NetSim are abstract, which means that they could be any kind of sensor or embedded device. Any data transmitted by these devices have to be in the form of 'IP Packets'. NetSim simulates the transmission of these IP packets. It does not focus on 'what is the application payload' being sent and is not concerned with data storage & analytics of this payload.

NetSim's Internet of Things (IoT) and Wireless Sensor Network (WSN) libraries stack comprises of

- Application Layer: Sensor App as well as applications such as Voice, Video, CBR etc.
- Transport Layer: UDP
- Network layer: AODV and RPL
- MAC and PHY layers: 802.15.4 Zigbee

NetSim models IoT as a WSN that connects to an Internetwork through a 6LowPAN Gateway. The 6LowPAN Gateway uses two interfaces: a Zigbee (802.15.4) interface and a WAN Interface. This WSN sends data to a 6LowPAN Gateway. The Zigbee interface allows wireless connectivity to the WSN while the WAN interface connects to an Internetwork.

IEEE 802.15.4 uses either Beacon Enabled or Disabled Mode for packet transmission. In Beacon Enabled Mode, nodes use slotted CSMA/CA algorithm for transmitting packets else they use Unslotted CSMA/CA.

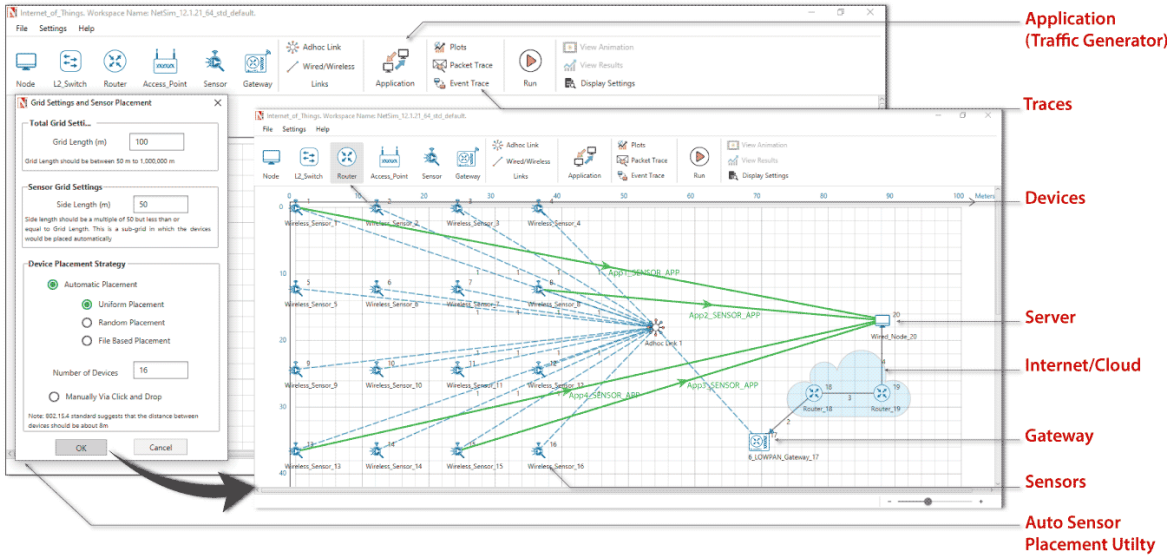


Figure 1-1: A typical IOT scenario in NetSim

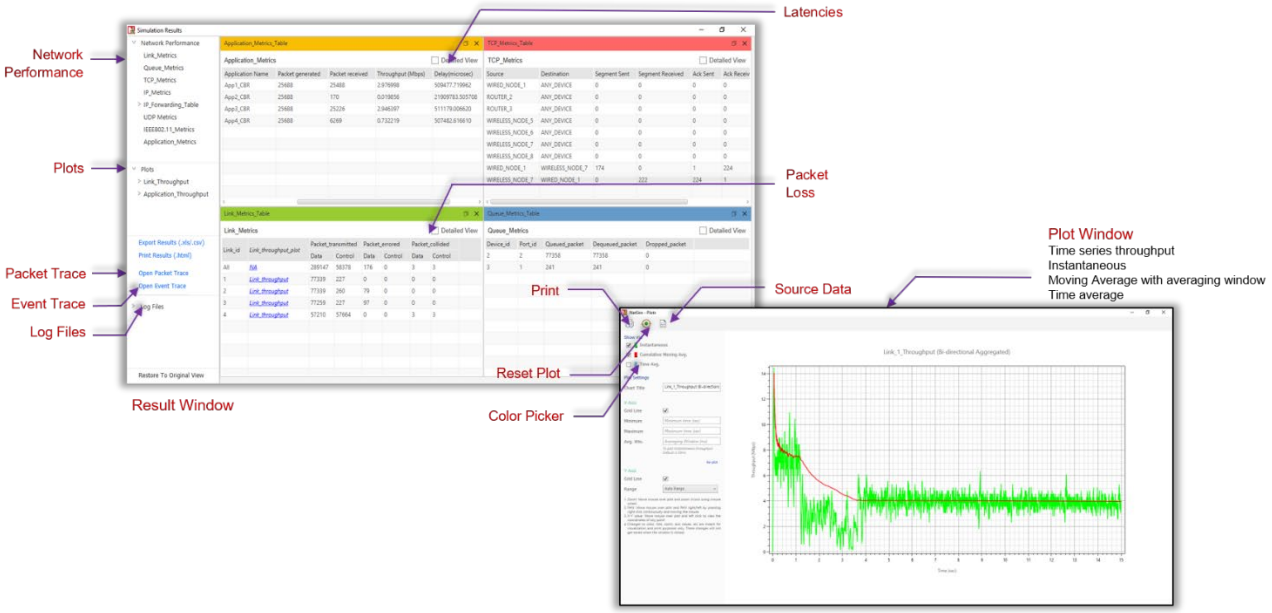


Figure 1-2: The Result dashboard and Plot window shown in NetSim after completion of simulation

2 Simulation GUI

In the Main menu select **New Simulation→ Wireless Sensor Networks** as shown **Figure 2-1.**

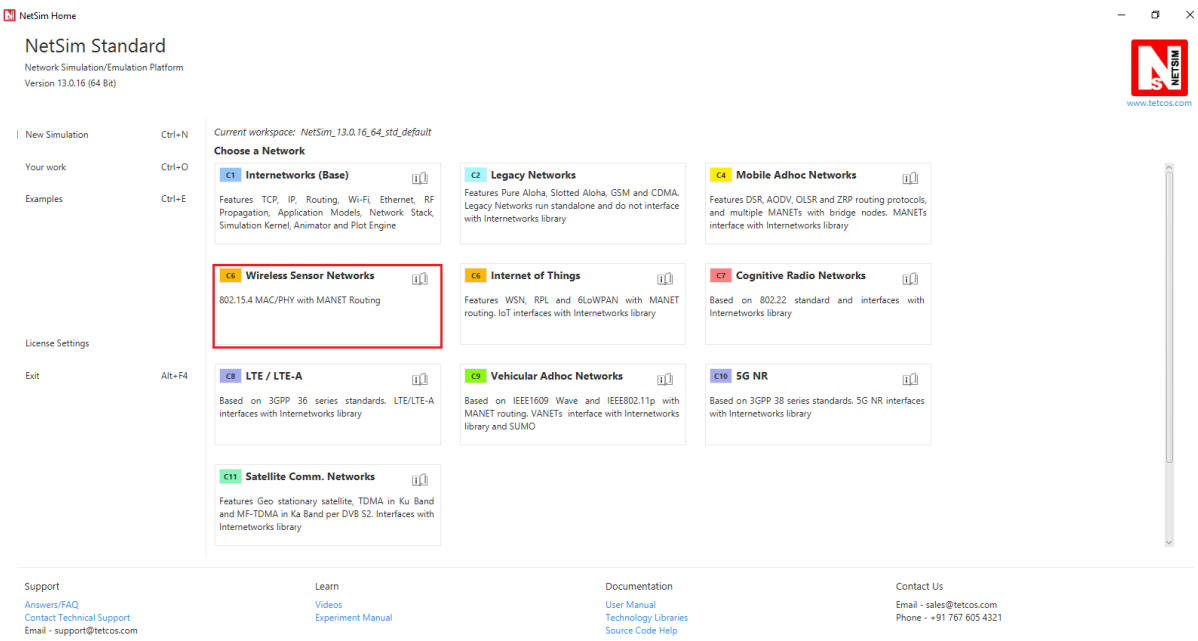


Figure 2-1: NetSim Home Screen

2.1 Create Scenario

2.1.1 Fast Configuration

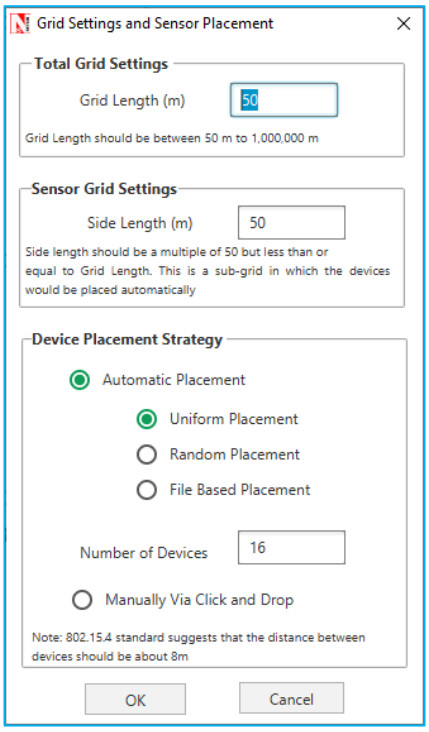


Figure 2-2: Fast Configuration window

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

Grid length: It is the area of simulation environment. Users can change the length of the grid in the range of 50-1000000m.

Side length: It specifies the area in the grid environment within which the devices will be placed. User can change the side length of the grid in the range of 50 - 1000000m. Side length should be multiple of 50. Side length should always be set to a value lesser than or equal to the Grid length.

Device Placement - Automatic Placement:

1. **Uniform Placement:** Devices will be placed uniformly with equal gap between the devices in area as specified inside length. This requires users to specify the number of devices as square number. For E.g. 1, 4, 9, 16 etc.
2. **Random Placement:** Devices will be placed randomly in the grid environment within the area as specified inside length.
3. **File Based Placement:** In order to place devices in user defined locations file-based placement option can be used. The file has the following general format:

<DEVICE_NAME>,<DEVICE_TYPE>,<X_COORDINATE>,<Y_COORDINATE>

Where,

DEVICE_NAME – is any name that will be assigned to the device.

DEVICE_TYPE – is the unique Device Identifier specific to each type of device in NetSim. Following table provides a list of all possible devices in MANET, WSN, and IOT Networks that support the Fast Configuration along with their respective device types:

NETWORK	DEVICE_TYPE
Manets	1. WIRELESSNODE 2. BRIDGE_WIREDNODE 3. BRIDGE_WIRELESSNODE 4. WIREDNODE 5. ROUTER 6. L2_SWITCH
WSN	1. Sensors 2. SinkNode

IOT	1. IOT_Sensors 2. LOWPAN_Gateway 3. WIREDNODE 4. WIRELESSNODE 5. IOT_ROUTER 6. ACCESSPOINT 7. L2_SWITCH

Table 2-1: Fast Configuration window support different networks

Note: *For more details about File Based Placement, refer Section 4.3*

1. **Number of Devices:** It is the total number of devices that is to be placed in the grid environment. It should be a square number in case of Uniform placement.
2. **Manually Via Click and Drop:** Selecting this option will load an empty grid environment where users can add devices manually by clicking and dropping the devices as required.

2.1.2 Wireless Sensor Networks

The devices that are involved in WSN are:

Wireless_Sensor - In general, sensors monitor and records the physical conditions of the environment which is then sent to a central location (Sink node) where the data is collated and analysed for further action. Sensors in NetSim are abstract in terms of what they sense, and NetSim focuses on the network communication aspects after sensing is performed.

WSN_Sink (in WSN): Sink node is the principal controller in WSN. All sensors send their data to this sink node. In NetSim, users can drop only one sink node in a WSN.

Ad-hoc Link: Ad hoc link depicts a decentralised type of wireless network. The network is ad hoc because it does not rely on any pre-existing infrastructure, such as routers in wired networks or access points in managed wireless networks. In NetSim, Ad hoc link are used to connect the Sensors and the Sink node. Ad hoc links are used here for a visual representation of connection of all the devices in an Ad hoc basis.

Note: *While designing a network, after dropping the sensor nodes and the sink node, click on the Adhoc link present in the top ribbon/toolbar and drop it inside the grid like you did for sensors and sink node. Once the Ad hoc link is present inside the grid, click on the same and now click on the other devices (say sensors or sink) you wish to connect. Similarly repeat the same procedure to connect all the devices to the Ad hoc link.*

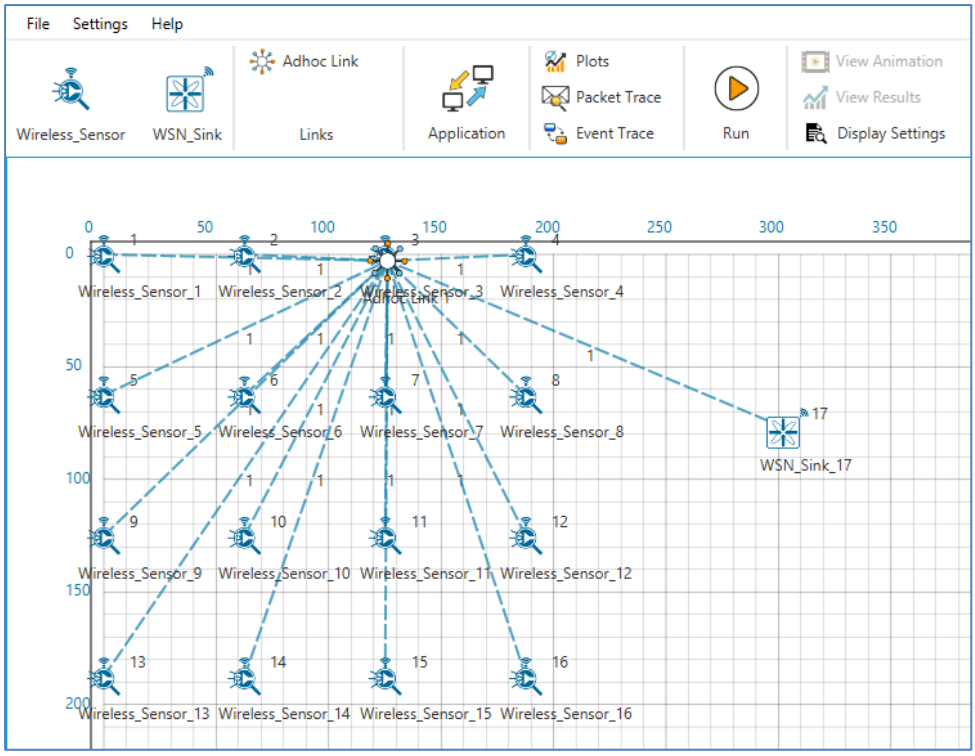


Figure 2-3: Network Topology of WSN

2.1.3 Internet of Things

The devices that are involved in IoT are:

IoT_Sensor - In general, sensors monitor and records the physical conditions of the environment which is then sent to a central location (Sink node) where the data is collated and analysed for further action. Sensors in NetSim are abstract in terms of what they sense, and NetSim focuses on the network communication aspects after sensing is performed.

LoWPAN Gateway (in IoT) - LoWPAN is an acronym of Low power Wireless Personal Area Networks. The LoWPAN IoT gateway functions as a border router in a LoWPAN network, connecting a wireless IPv6 network to the Internet. The wired portion of the network in IoT runs IPv4 whereas the wireless portion runs IPv6. The IPv6 routing protocols supported as AODV and RPL.

Ad-hoc Link: Ad hoc link depicts a decentralised type of wireless network. The network is ad hoc because it does not rely on any pre-existing infrastructure, such as routers in wired networks or access points in managed wireless networks. In NetSim IoT, Ad hoc link are used to connect the IoT_Sensors and the 6LowPAN_Gateway. Ad hoc links are used here for a visual representation of connection of all the devices in an Ad hoc basis.

Users can also add routers and nodes as shown below. Routers can be connected to the 6LoWPAN-Gateway and nodes/switches can be connected to routers using wired/wireless links.

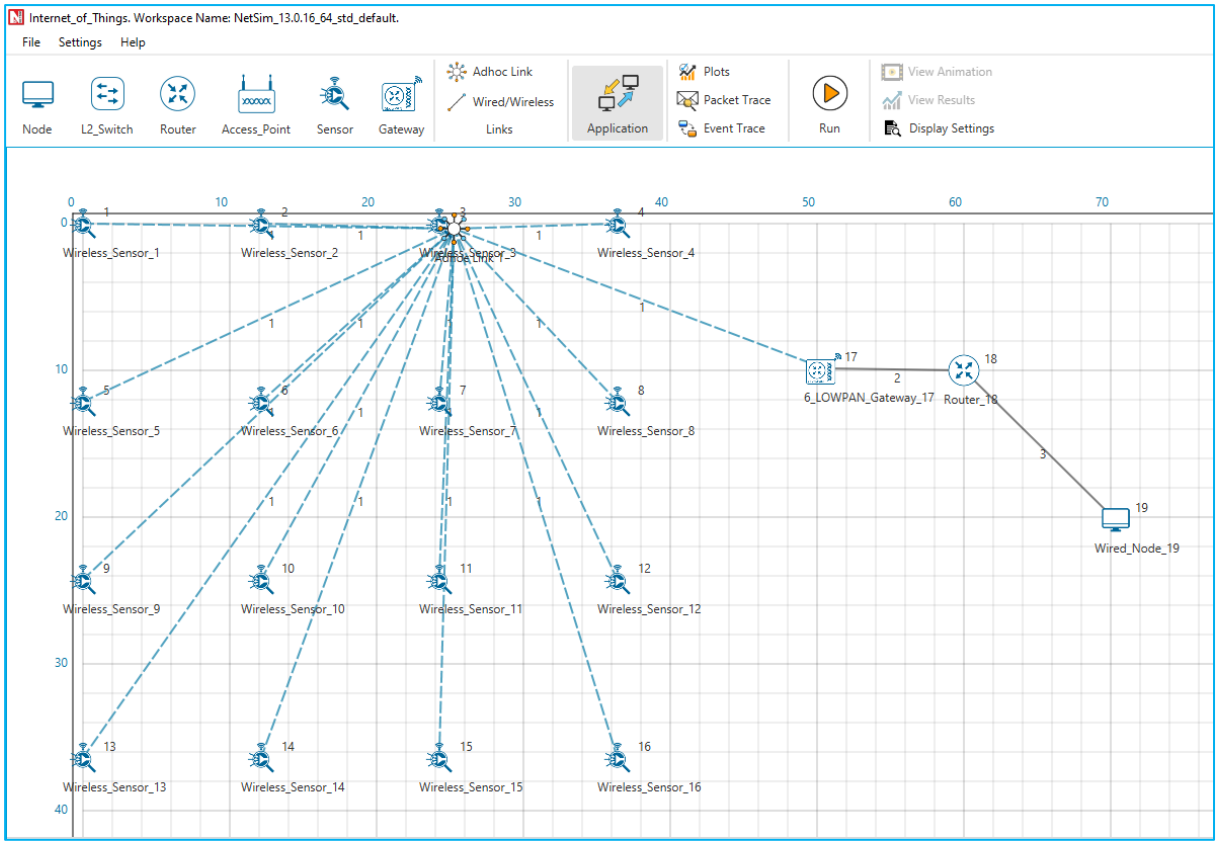


Figure 2-4: Internet of Things

2.1.4 Differences between IoT and WSN in NetSim

WSN	IoT
WSN consists of a network of only sensors.	IOT has a gateway which can be used to connect to internetworks (having routers, switches, APs etc.).
WSN runs IPv4 and features a sink (not a gateway).	IOT runs IPv6 in the sensor network (802.15.4 MAC/PHY) and IPv4 on the inter-network portion.
Routing protocols in NetSim WSN include, DSR, AODV, OLSR, and ZRP.	Routing protocols in NetSim IoT include, AODV and RPL.

Table 2-2: Differences between IoT and WSN in NetSim

Note: Please refer MANET Technology library for working of AODV, DSR, OLSR and ZRP.

2.1.5 Device Attributes

GENERAL PROPERTIES

Right click on any sensor and select properties. The general properties of the sensor are:

- **Device name** is the name of sensor which is editable and will reflect in the GUI before and after simulation.
- **X /Lat and Y/Lon** are the coordinates of a sensor.
- **Z coordinate** by default will be zero (this is reserved for future use).

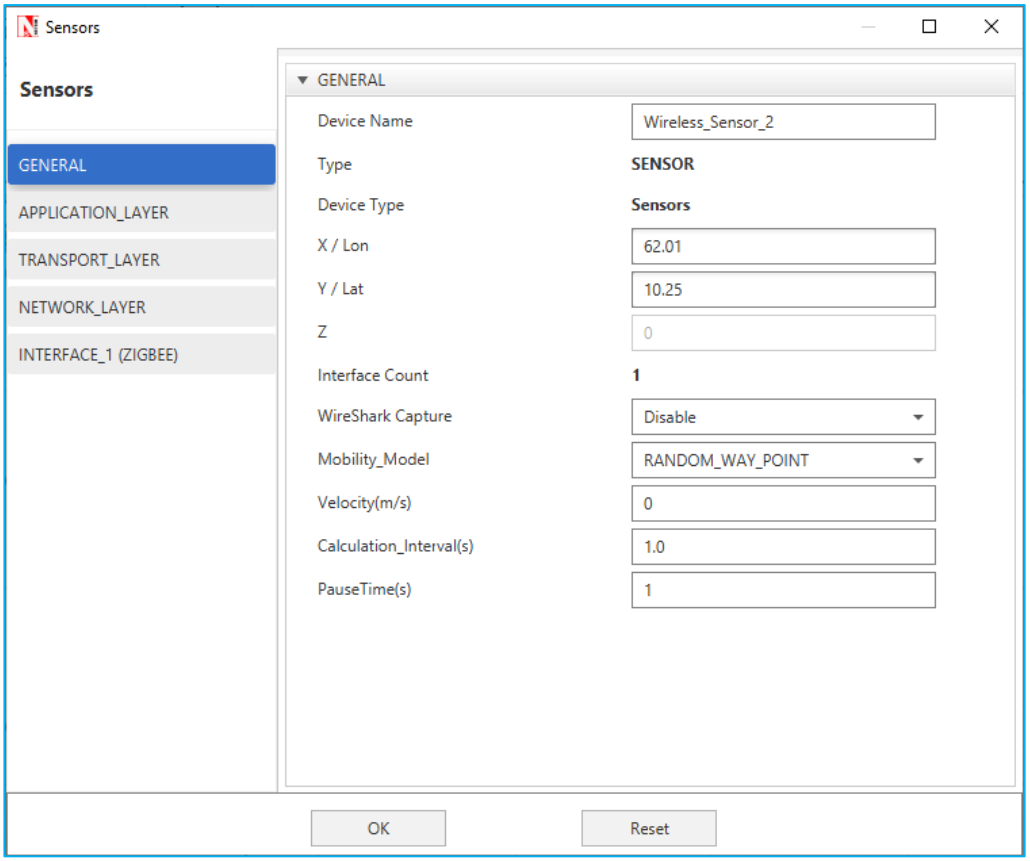


Figure 2-5: General Properties window for Sensor

Interface count is 1 since sensors share the wireless Multipoint-to-Multipoint medium.

Mobility Models: Mobility models can be used to model movement of sensors. The mobility models provided in NetSim are:

- **Random Walk mobility model**: It is a simple mobility model based on random directions and speeds.
- **Random Waypoint Mobility Model**: It includes pause time between changes in direction and/or speed.
- **Group mobility**: It is a model which describes the behavior of sensors as they move together i.e., the sensors having common group id will move together.
- **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)
    - Pedestrain_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 assume that the pedestrian stops at traffic lights. The stop_probability represents the probability of encountering a traffic light. This is

checked for every Calcuation_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 pedestrian continuing in the same direction, taking a left, taking a U turn and taking a right respectively.

A new speed is chosen randomly after evert stop. Min_speed ≤ Speed ≤ Max_Speed.

The maximum number of stops and starts is 10.

- **File Based mobility:** In File Based Mobility, users can write their own custom mobility models and define the movement of the mobile users. The name of the trace file generated should be kept as mobility.txt and it should be in the **NetSim Mobility File format**.

APPLICATION PROPERTIES – Transport Protocol, by default set to UDP. To run with TCP, users have to select TCP protocol from the drop down.

NETWORK LAYER- NetSim WSN, supports the following MANET routing protocols.

DSR (Dynamic source routing): Note that in wireless sensor networks, by default Link Layer Ack is enabled. If Network Layer ack is enabled users must set DSR_ACK in addition to Zigbee_ACK in MAC layer.

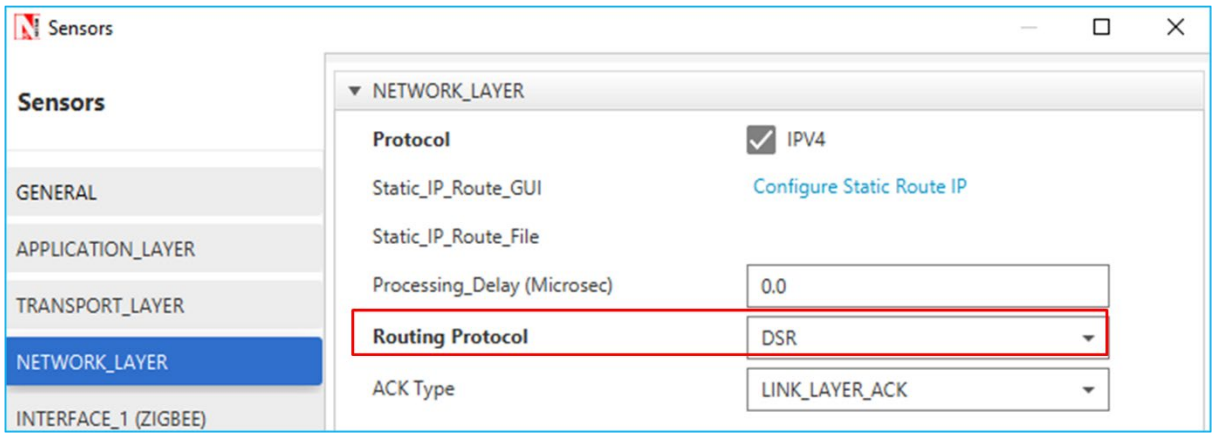


Figure 2-6: Network Layer Properties Window - DSR Protocol

AODV (Ad-hoc on-demand distance vector routing):

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. Some of the features implemented in NetSim are,

- RREQ, RREP and RERR messages.

- Hello message.
- Interface with other MAC/PHY protocols such as 802.15.4, TDMA / DTDMA.

ZRP (Zone routing protocol): For interior routing mechanism NetSim uses OLSR protocol.

Hello interval describes the interval in which it will discover its neighbor routes.

Refresh interval is the duration after which each active node periodically refresh routes to itself.

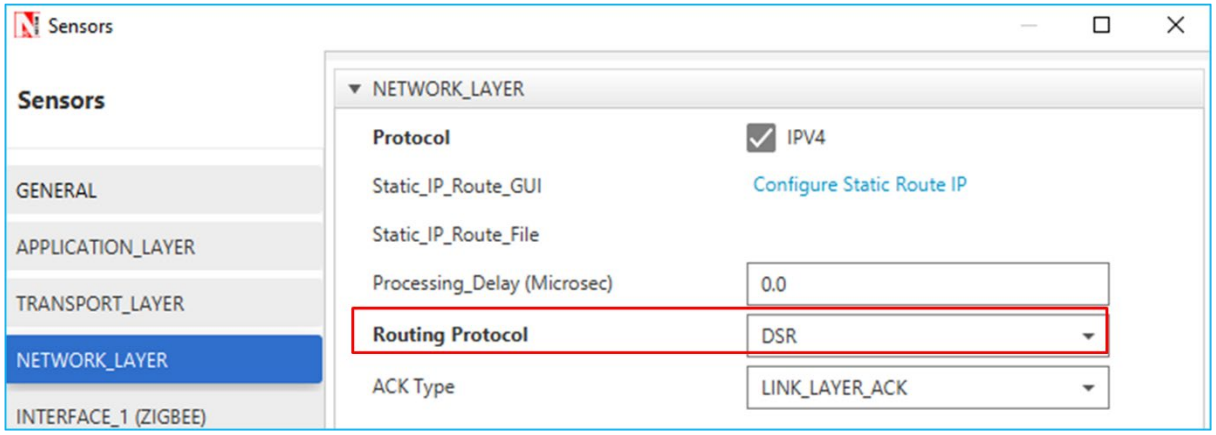


Figure 2-7: Network Layer Properties Window - ZRP Protocol

TC Interval is a Topology control messages are the link state signaling done by OLSR. These messages are sent at TC interval every time.

Zone radius: After dividing the network range of the divided network will be based on zone radius. 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

OLSR (Optimized link State Routing): Except zone radius all the parameters are similar to ZRP.

DATALINK LAYER

802.15.4 (Zigbee Protocol) runs in MAC layer. In the sink node or pan coordinator properties users can configure the Beacon frames and the superframe structure**.**

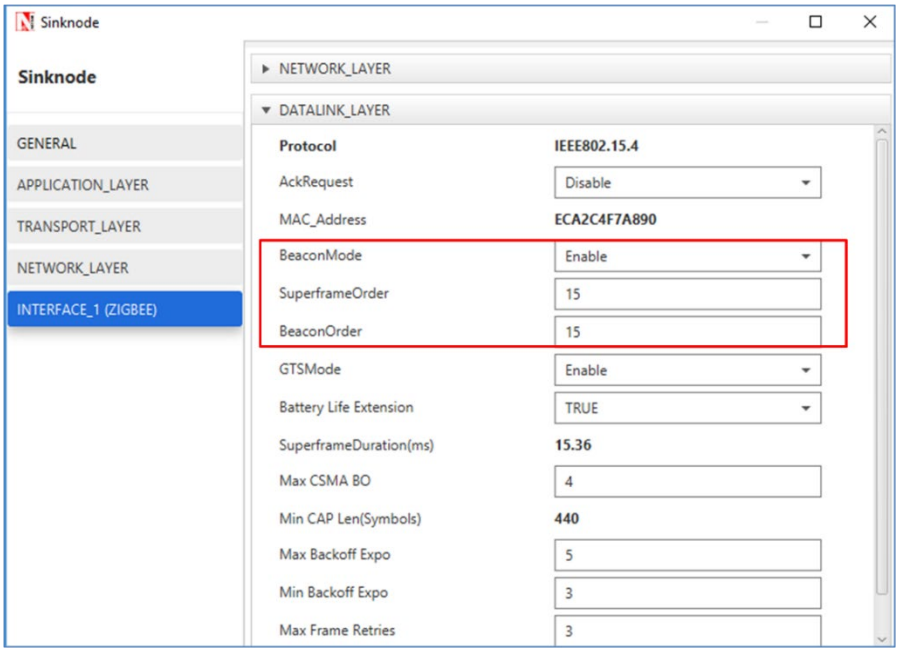


Figure 2-8: Datalink layer properties window for sinknode

Superframe Order – It describes the length of the active portion of the Superframe, which includes the beacon frame. Range is from 0-15.

Beacon Order- Describes the interval at which coordinate shall transmit its beacon frames. Range is from 1-15.

GTS Mode (Guaranteed Time Slot) – If it is enabled it allows a device to operate on the channel within a portion of the super frame that is dedicated (on the PAN) exclusively to the device.

Battery life Extension subfield is 1 bit in length and shall be set to one if frames transmitted to the beaconing device.

Superframe Duration is divided into 16 equally sized time slots, during which data transmission is allowed. The value of supreframe duration by default is 15.36ms.

Max CSMA Backoff is the CSMA-CA algorithms will attempts before declaring a channel access failure. Having range 0-5.

Minimum CAP length is the minimum number of symbols forming the Contention access period. This ensures that MAC commands can still be transferred to devices when GTSs (Guaranteed time slots) are being used.

Max and Min backoff exponent values of CSMA-CA algorithms having range 3-5.

Max frame retries is the total number of retries after failed attempts.

Unit Backoff period is the number of symbol forming the basic time period used by the CSMA-CA algorithms.

PHYSICAL LAYER

The frequency band used in NetSim WSN simulations is 2.4 GHz, and the bandwidth is 5 MHz. NetSim simulates a single channel ZigBee network and does not support multiple channels.

Data rate is the number of bits that are processed per unit of time. The data rate is fixed at 250 kbps per the 802.15.4 standard.

Chip Rate: A chip is a pulse of direct-sequence spread spectrum code, so the chip rate is the rate at which the information signal bits are transmitted as pseudo random sequence of chips.

Modulation technique: O-QPSK (Offset quadrature phase shift keying) sometimes called as staggered quadrature phase shift keying is a variant of phase-shift keying modulation using 4 different values of the phase to transmit.

MinLIFSPeriod is minimum long inter frame spacing Period. It's a time difference between short frame and long frame in unacknowledged case and time difference between short frame and Acknowledged in acknowledge transmission.

SIFS (Short inter frame Symbol) is generally the time for which receiver wait before sending the CTS (Clear To Send) & acknowledgement package to sender, and sender waits after receiving CTS and before sending data to receiver. Its main purpose is to avoid any type of collision. Min SIFS period is the minimum number of symbols forming a SIFS period.

Phy SHR duration is the duration of the synchronization header (SHR) in symbol for the current PHY.

Phy Symbol per Octet is number of symbol per octet for the current PHY.

Turn Around Time is transmitter to receiver or receiver to transmitter turnaround time is defined as the shortest time possible at the air interface from the trailing edge of the last chip (of the first symbol) of a transmitted PLCP protocol data unit to the leading edge of the first chip (of the first symbol) of the next received PPDU.

CCA (Clear Channel assessment) is carrier sensing mechanisms in Wireless Network. Here is the description:

- **Carrier Sense Only:** It shall report a busy medium only upon the detection of a signal complaint with this standard with the same modulation and spreading characteristics of the PHY that is currently in use by the device. This signal may be above or below the ED threshold.

- **Energy Detection:** It shall report a busy medium upon detecting any energy above the ED threshold.
- **Carrier Sense with Energy Detection:** It shall report a busy medium using a logical combination of detection of a signal with the modulation and spreading characteristics of this standards and Energy above the ED threshold, where the logical operator may be AND or OR.

Receiver sensitivity is the minimum magnitude of input signal required to produce a specified output signal having a specified signal-to-noise ratio, or other specified criteria. It's up to our calculation what we want a receiver sensitivity.

Receiver ED threshold is intended for use by a network layer as part of a channel selection algorithms. It is an estimate of the received signal power within the bandwidth of the channel. No attempt is made to identify or decode signal on the channel. If the received signal power is greater than the ED threshold value then the channel selection algorithms will return false.

Transmitter Power is the signal intensity of the transmitter. The higher the power radiated by the transmitter's antenna the greater the reliability of the communication system. And connection medium is Wireless.

Reference Distance (d_0) is known as the reference distance and the value of d_0 is usually defined in the pathloss model or in the standard. PL_{do} is the pathloss at reference distance. In 805.15.4, the standard defines $d_0 = 8m$ and $PL_{d0} = 58.5\ dB$. Please see Propagation-Model.pdf manual for more information.

POWER MODEL

- **Power sourec** can be battery or main line. This model in NetSim is used for energy calculations. In case of battery following parameters will be considered: -
- **Recharging current** is the current flow during recharging. Range is from 0-1mA.
- **Energy Harvesting** is the process by which energy is derived from external source, captured, and stored. NetSim supports an abstract Energy Harvesting model a specified amount of energy (calculated from recharging current and voltage specified) is added to the remaining energy of the node periodically to replenish the battery.
- **Initial Energy** is the battery energy range is from 0 to 1000mW.
- **Transmitting current** for transmitting the power. Range 0-20mA. Transmit power and transmit current are independent in NetSim. Since the focus of NetSim is packet simulation, the power modeling is abstract. It is left to the user to change the transmit current accordingly (when increasing/decreasing the transmit power) if the user's goal is to study power consumption.
- **Idle mode** is the current flow during the ideal mode range is between 0-20mA.

- **Voltage** is a measure of the energy carried by the charge. Range is from 0-10V.
- **Received current** is the current required to receive the data having range from 0-10mA.
- **Sleep mode current** is current flowing in sleep mode of battery range is from 0-20mA.

Note: The resultant energy metrics and their definitions are provided in NetSim_User_Manual in the Outputs section.

The following table shows the properties of sensor in NetSim.

Sensor Properties

Global properties (and default settings)	
Network layer	
Routing protocol	DSR
ACK _Type	LINK_LAYER_ACK
Data link layer	
ACK request	Enable
Max Csma BO	4
Max Csma Exponent	5
Min Csma Exponent	3
Max frame retires	3
Local properties (and Default settings)	
Physical layer	
phySHRduration(symbols)	3
Physymbolperoctet	0.4
CCA mode	CARRIER_SENSE_ONLY
Reciever sensitivity(dbm)	-85
ED_Threshold (dbm)	-95
Transmitter power(dbm)	1
Power	
Power source	Battery
Energy harvesting	ON
Recharging current (mA)	0.4
Initial energy (mw)	1000
Transmitting current (mA)	8.8
Idle mode current (mA)	3.3
Voltage (v)	3.6
Receiving current (mA)	9.6
Sleep mode current (mA)	0.237

Table 2-3: MAC and PHY layer properties of sensor

2.2 Set Node, Link and Application Properties

- Users need to connect the sensors and **LoWPAN gateway** using adhoc links.
- Interconnection among other devices is same as in Internetworks.
- **LoWPAN gateway** can be connected with router using links.
- **Right click** on the appropriate node or link and select Properties. Then modify the parameters according to the requirements.
- Routing Protocol in Application Layer of router and all user editable properties in DataLink Layer and Physical Layer of Access Point and Wireless Node are Global/Local i.e. changing properties in one node will automatically reflect in the others in that network.
- In Sensor Node, Routing Protocol in Network Layer and all user editable properties in DataLink Layer, Physical Layer and Power are Global/Local i.e. changing properties in one node will automatically reflect in the others in that network. The following are the main properties of sensor node in PHY and Datalink layers as shown **Figure 2-9/Figure 2-10/Figure 2-11.**

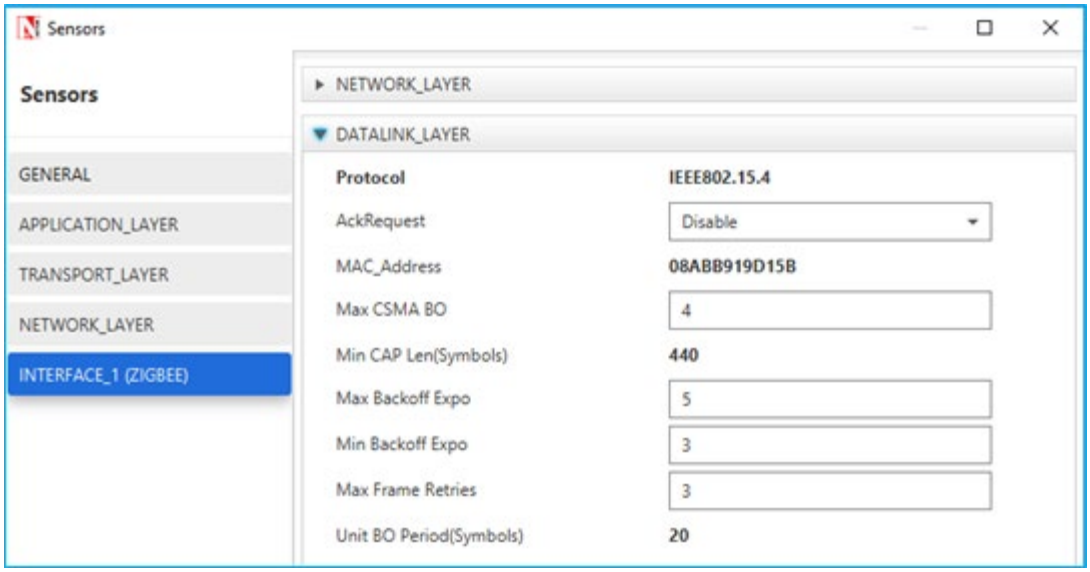


Figure 2-9: Datalink layer properties window for sensor

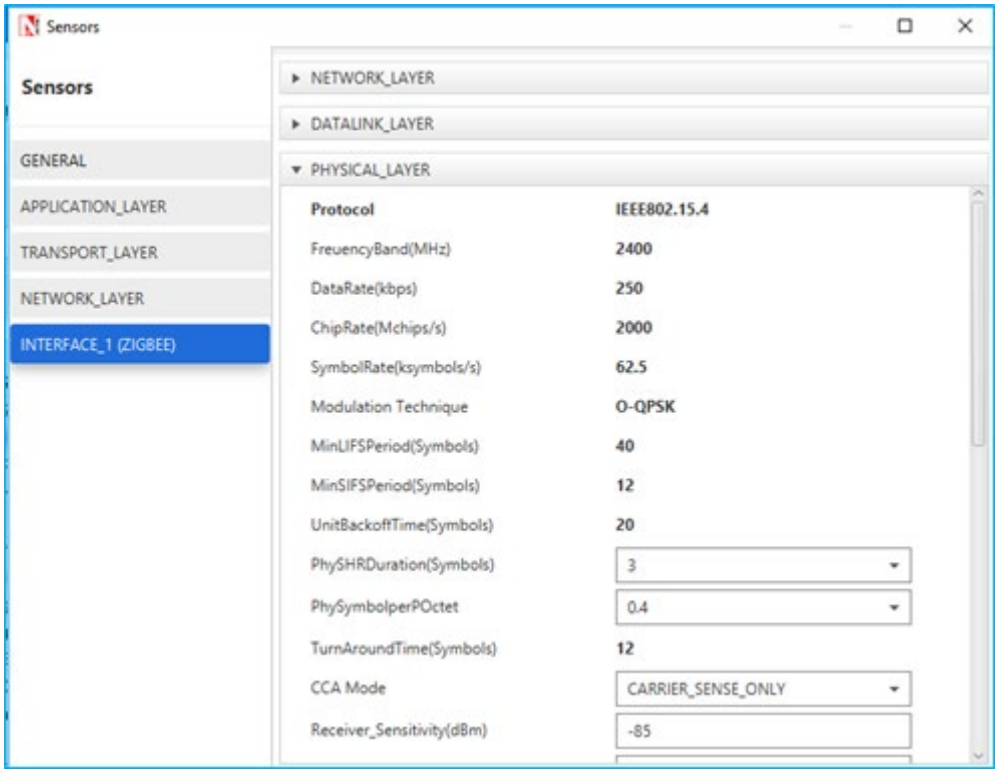


Figure 2-10: PHY layer properties window for sensor

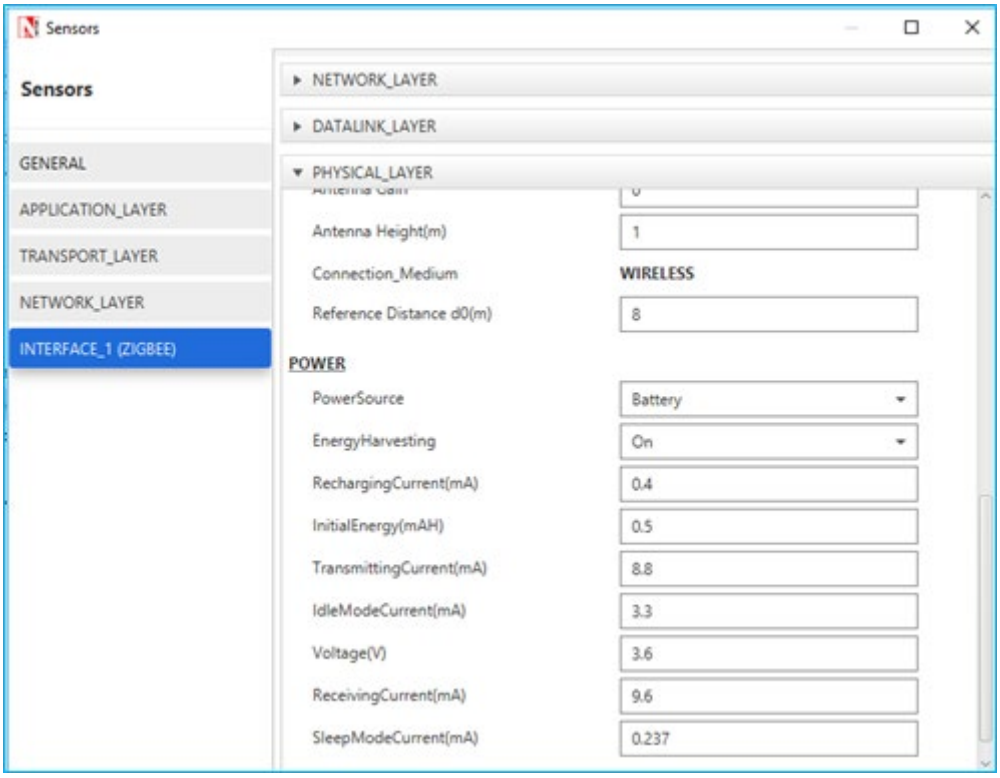


Figure 2-11: Battery Model for Sensor

- Set the values according to requirement and click OK.
- Click on the Application icon present on the ribbon and set properties. Multiple applications can be generated by using add button in Application properties.

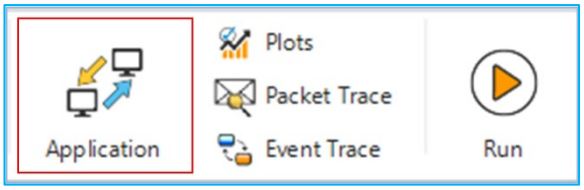


Figure 2-12: Application icon present on top ribbon

- Set the values according to requirement and click OK.

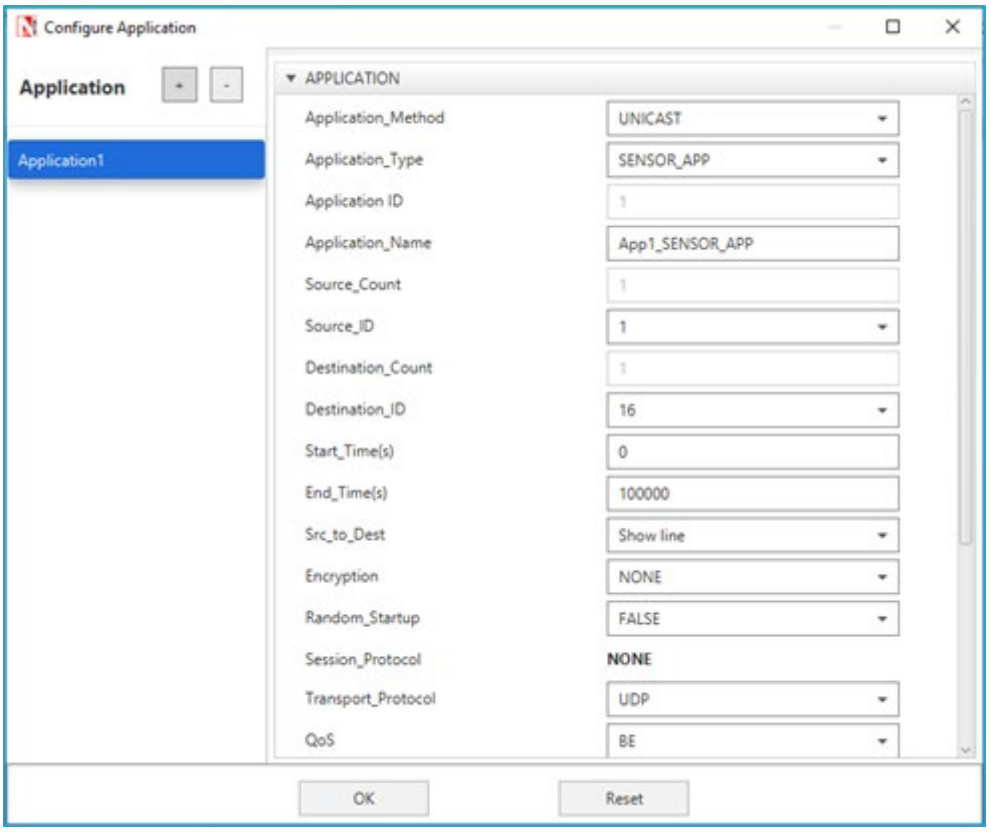


Figure 2-13: Application Configuration window

Detailed information on Application properties is available in section 6 of NetSim User Manual.

2.2.1 Setting Static Routes

In Device Properties > Network layer > Configure static route IP, users can set static routes. When static routes are set the dynamic routing protocol entries are overwritten by the static routing entries. Static route configured explained in Internetworks technology library document, Section Configuring Static Routing in NetSim

Static route option is available for all sensors in WSN.

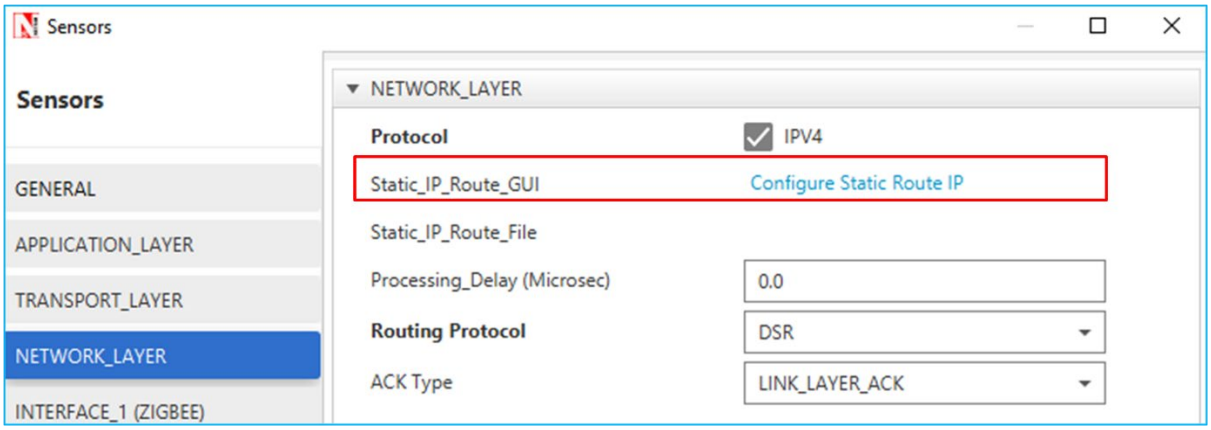


Figure 2-14: Static Route configuration window

The Static routes option is not available in wireless portion of the IoT network as IoT devices work with IPv6 network addressing. The devices present in the wired portion of network say have IPv4 addressing. Hence static routes can be configured in the wired section (till the gateway) of an IoT network

2.3 Enable Packet Trace, Event Trace & Plots (Optional)

Click Packet Trace / Event Trace icon in the tool bar and check Enable Packet Trace / Event Trace check box and click OK. To get detailed help, please refer sections 8.4 and 8.5 in User Manual. Select Plots icon for enabling Plots and click OK.

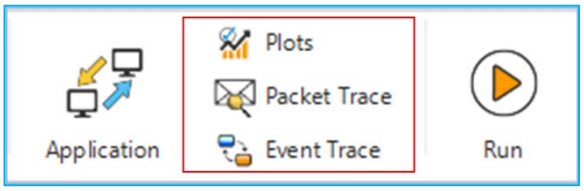


Figure 2-15: Enable Packet Trace, Event Trace & Plots options on top ribbon

2.4 Run Simulation

Click on **Run Simulation** icon on the top toolbar.

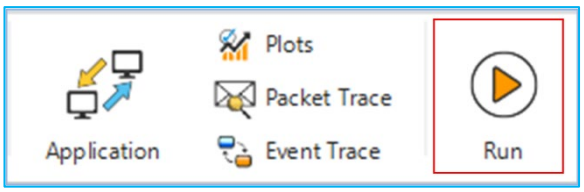


Figure 2-16: Run Simulation options on top ribbon

Set the Simulation Time and click on OK.

3 Model Features

3.1 L3 Routing: DSR, OLSR, ZRP and AODV

Refer to the MANETs technology library (PDF) document for detailed information. Note that:

- WSN supports DSR, OLSR, ZRP and AODV protocols
- IOT supports AODV and RPL protocol, since only AODV and RPL have IPv6 support in NetSim.

3.2 L3 Routing: RPL Protocol

Routing Protocol for Low power and Lossy Networks (RPL) Overview

Low-power and Lossy Networks consist largely of constrained nodes (with limited processing power, memory, and sometimes energy when they are battery operated). These routers are interconnected by lossy links, typically supporting only low data rates that are usually unstable with relatively low packet delivery rates. Another characteristic of such networks is that the traffic patterns are not simply point-to-point, but in many cases point-to-multipoint or multipoint-to-point.

RPL Routing Protocol works in the Network Layer and uses IPv6 addressing. It runs a distance vector routing protocol based on Destination Oriented Directed Acyclic Graph (DODAGs).

Terminology of RPL routing protocol:

- **DAG (Directed Acyclic Graph)**: A directed graph having the property that all edges are oriented in such a way that no cycles exist. All edges are contained in paths oriented toward and terminating at one or more root nodes.
- **DAG root**: A DAG root is a node within the DAG that has no outgoing edge. Because the graph is acyclic, by definition, all DAGs must have at least one DAG root and all paths terminate at a DAG root. In NetSim, only single root is possible. i.e. the 6LowPAN Gateway
- **Destination-Oriented DAG (DODAG)**: A DAG rooted at a single destination, i.e., at a single DAG root (the DODAG root) with no outgoing edges.
- **Up:** Up refers to the direction from leaf nodes towards DODAG roots, following DODAG edges. This follows the common terminology used in graphs and depth-first search, where vertices further from the root are "deeper" or "down" and vertices closer to the root are "shallower" or "up"
- **Down:** Down refers to the direction from DODAG roots towards leaf nodes, in the reverse direction of DODAG edges. This follows the common terminology used in

graphs and depth-first search, where vertices further from the root are "deeper" or "down" and vertices closer to the root are "shallower" or "up"

- **Rank**: A node's Rank defines the node's individual position relative to other nodes with respect to a DODAG root. Rank strictly increases in the Down direction and strictly decreases in the Up direction.
- **RPLInstanceID:** An RPL Instance ID is a unique identifier within a network. DODAGs with the same RPLInstanceID share the same Objective Function.
- **RPL instance**: When we have one or more DODAG, then each DODAG is an instance. An RPL Node may belong to multiple RPL Instances, and it may act as router in some and as a leaf in others. Any sensor can be configured as a Router or Leaf. Leaf nodes doesn't take part in RPL routing.
- **DODAG ID**: Each DODAG has an IPV6 ID. This ID is given to its root only. And as the root doesn't change ID also don't change
- **Objective Function (OF):** An OF defines how routing metrics, optimization objectives, and related functions are used to compute Rank. Furthermore, the OF dictates how parents in the DODAG are selected and, thus, the DODAG formation.

3.2.1 RPL Objective Function

The objective function in NetSim RPL seeks to find the route with the best link quality. The objective function:

static UINT16 compute_candidate_rank(NETSIM_ID d, PRPL_NEIGHBOR neighbour) can be found in **Neighbor.c** under the RPL project**.**

Link quality calculations, available in Zigbee Project **802.15.4 c** file with function **get_link_quality( )**:

$$L_q = (1 - \left(\frac{p}{rs}\right)$$

where **p = received power (dBm)** and **rs = Receiver sensitivity (dBm)**

And Final

$$Link\ Quality = \frac{Sending\ Link\ Quality + Receving\ Link\ Quality}{2}$$

The rank calculations are done in **Neighbour.c** in RPL project and is

$$Rank = (Max_{increment} - Min_{increment}) * \left(1 - L_q\right)^2 + Min_{increment}$$

The link quality in this case is based on received power and can be modified by the user to factor in distance, delay etc, Link quality is calculated by making calls to the functions in the following order:

1. **compute_candidate_rank()** – RPL \Neighbor.c
2. **fn_NetSim_stack_get_link_quality()** - NetSim network stack which in turn calls
3. **zigbee_get_link_quality()** – ZigBee \802_15_4.c

The function **fn_NetSim_stack_get_link_quality()** is part of NetSim's network stack which is closed to user. However the function **zigbee_get_link_quality()** is open to the users and can be modified if required.

3.2.2 Topology Construction

NetSim IOT WSNs do not typically have predefined topologies, for example, those imposed by point-to-point wires, so RPL has to discover links and then select peers sparingly. RPL routes are optimized for traffic to or from one or more roots that act as sinks for the topology. As a result, RPL organizes a topology as a Directed Acyclic Graph (DAG) that is partitioned into one or more Destination Oriented DAGs (DODAGs), one DODAG per sink.

RPL identifiers: RPL uses four values to identify and maintain a topology:

- The first is an RPLInstanceID. An RPLInstanceID identifies a set of one or more Destination Oriented DAGs (DODAGs). A network may have multiple RPLInstanceIDs, each of which defines an independent set of DODAGs, which may be optimized for different Objective Functions (OFs) and/or applications. The set of DODAGs identified by an RPLInstanceID is called a RPL Instance. All DODAGs in the same RPL Instance use the same OF
- The second is a DODAGID. The scope of a DODAGID is a RPL Instance. The combination of RPLInstanceID and DODAGID uniquely identifies a single DODAG in the network. A RPL Instance may have multiple DODAGs, each of which has an unique DODAGID
- The third is a DODAGVersionNumber. The scope of a DODAGVersionNumber is a DODAG. A DODAG is sometimes reconstructed from the DODAG root, by incrementing the DODAGVersionNumber. The combination of RPLInstanceID, DODAGID, and DODAGVersionNumber uniquely identifies a DODAG Version
- The fourth is Rank. The scope of Rank is a DODAG Version. Rank establishes a partial order over a DODAG Version, defining individual node positions with respect to the DODAG root.

DIS (DODAG Information Solicitation) transmission:

Root sends DIS message to the Router/Leaf which are in range. The Router in turn broadcasts its further and so on.

DIO (DODAG Information Object) transmission:

RPL nodes transmit DIOs using a Trickle Timer. This message is multicasted downwards in a DODAG. With DIO child parent relationship and sibling relationship is established.

DODAG Construction

- Nodes periodically send link-local multicast DIO messages.
- Stability or detection of routing inconsistencies influence the rate of DIO messages.
- Nodes listen for DIOs and use their information to join a new DODAG, or to maintain an existing DODAG.
- Nodes may use a DIS message to solicit a DIO as shown below.

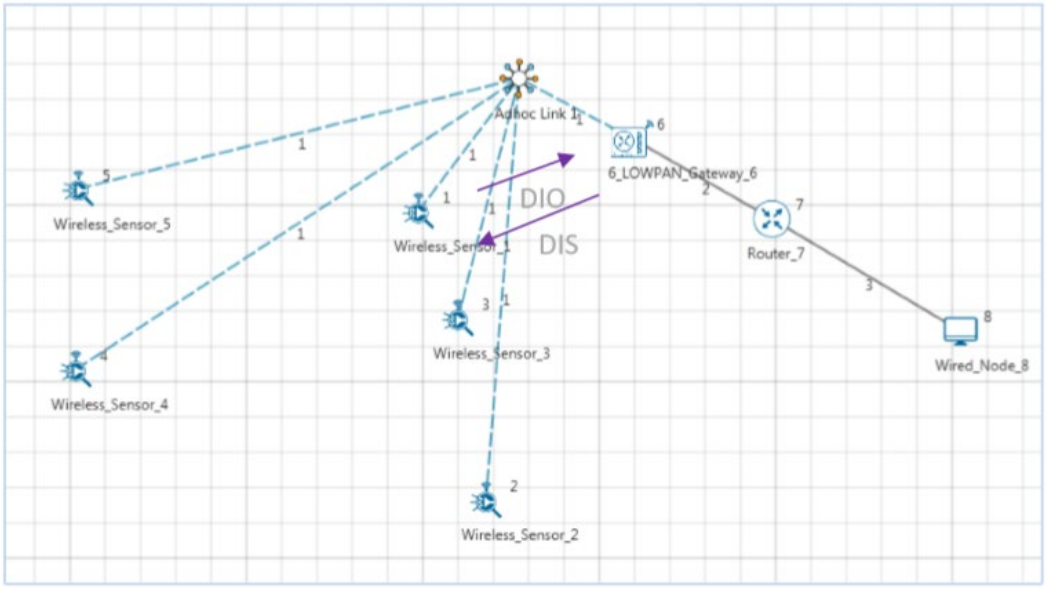


Figure 3-1: Exachnge DIO/DIS Control message for Sensor and Lowpan gateway

- Rank is then established. Rank is decided based on the DIS message received from the Root and the link quality.
- Based on information in the DIOs the node chooses parents to the DODAG root
- As a Result, the nodes follow the upward routes towards the DODAG root.
- If the destination is unreachable then the root will drop the packet.
- Note that DIS messages are sent by the sensors which are not part of the DODAG. The sensors which are part of the DODAG and which received the DIO message will send the DAO message in return, whereas the sensors which did not receive the DIO messages will send the DIS message.

3.2.3 RPL Log File

Once simulation is completed, users can access the rpl_log file from the results dashboard as shown below **Figure 3-2**.

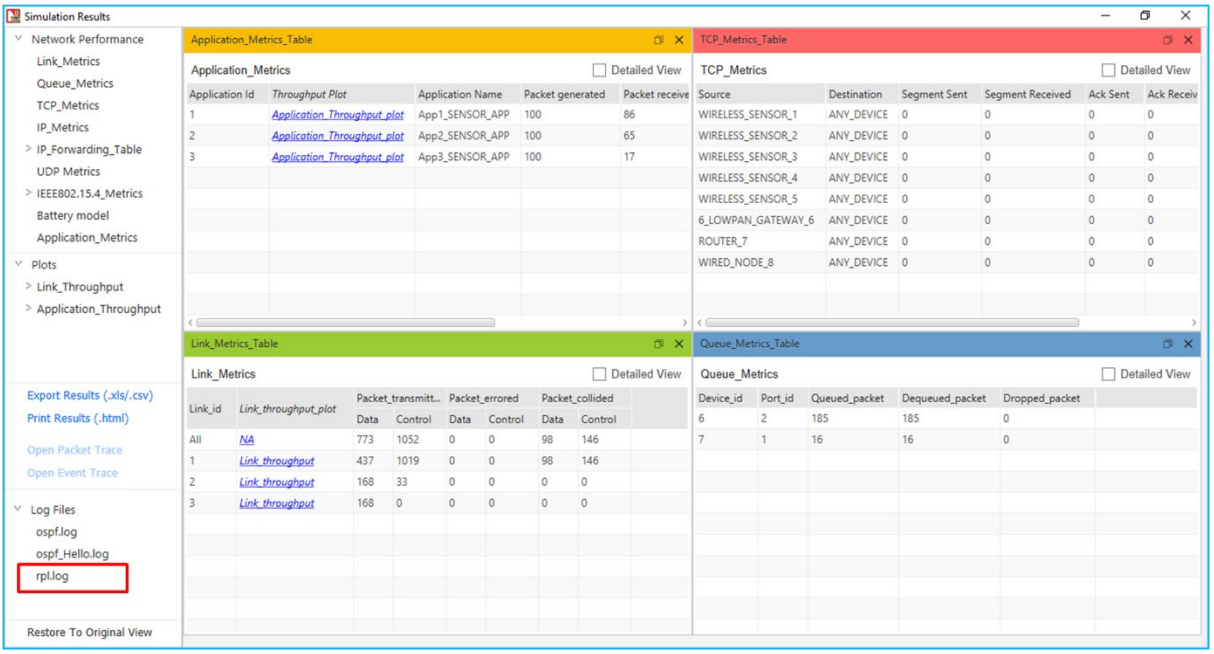


Figure 3-2: Results dashboard window

However, to get detailed information related to Rank Calculations the DEBUG_RPL preprocessor directive needs to be uncommented in the code.

Procedure to get detailed RPL log file:

- Go to NetSim Home page and click on Your work.
- Click on Workspace Options and then click on Open Code and open the codes in Visual Studio. Set Win32 or x64 according to the NetSim build which you are using.
- Go to the RPL Project in the Solution Explorer. Open RPL.h file and change //#define DEBUG_RPL to #define DEBUG_RPL as shown below:

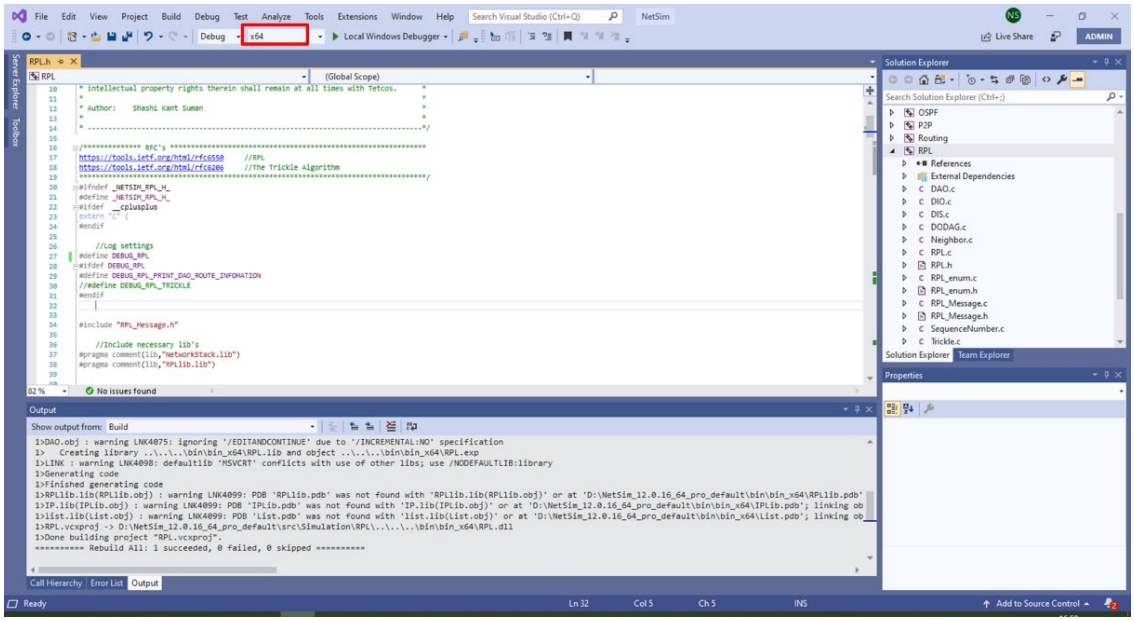


Figure 3-3: Visual Studio

- Right click on the **RPL** project in the solution explorer and click on rebuild.
- After the RPL project is rebuild successful, go back to the network scenario.

Now after any IoT-RPL simulation, the RPL log file will contain detailed information about the DODAG formation. An example rpl_log file is shown below **Figure 3-4.**

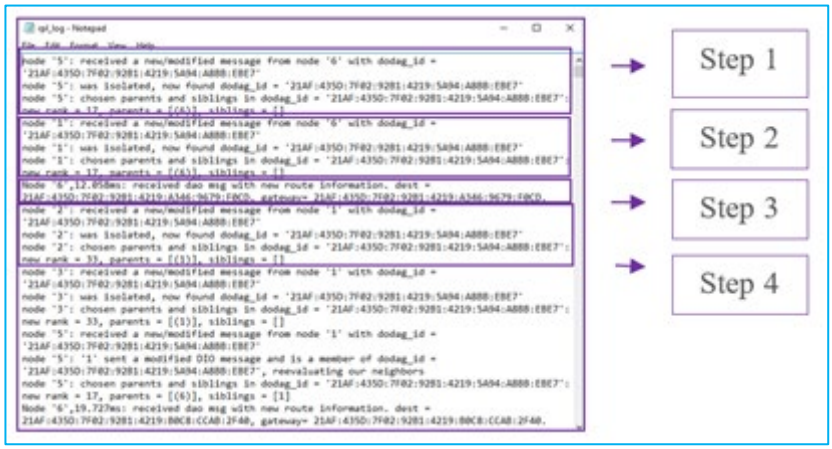


Figure 3-4: RPL Log file

Explanation of the log file:

Step 1:

- Node 5 receives a DIO msg from Node 6 (i.e. root).
- Node 5 finds the DODAG id
- Based on the DIO message received from Node 6, Node 5 choses its “Parent as Node 6” and establishes its “New Rank = 17”. It doesn’t have any siblings.

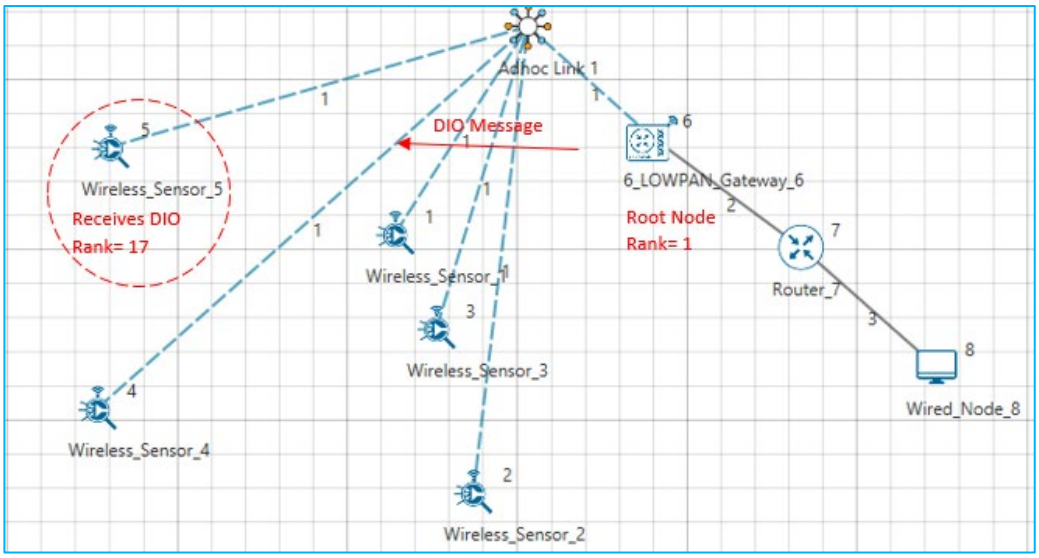


Figure 3-5: Node 5 choses its “Parent as Node 6 - New Rank = 17

Step 2:

- Node 1 receives a DIO msg from Node 6 (i.e. root).

- Node 1 finds the DODAG id
- Based on the DIO message received from Node 6, Node 1 choses its “Parent as Node 6” and establishes its “New Rank = 17”. It doesn’t have any siblings.

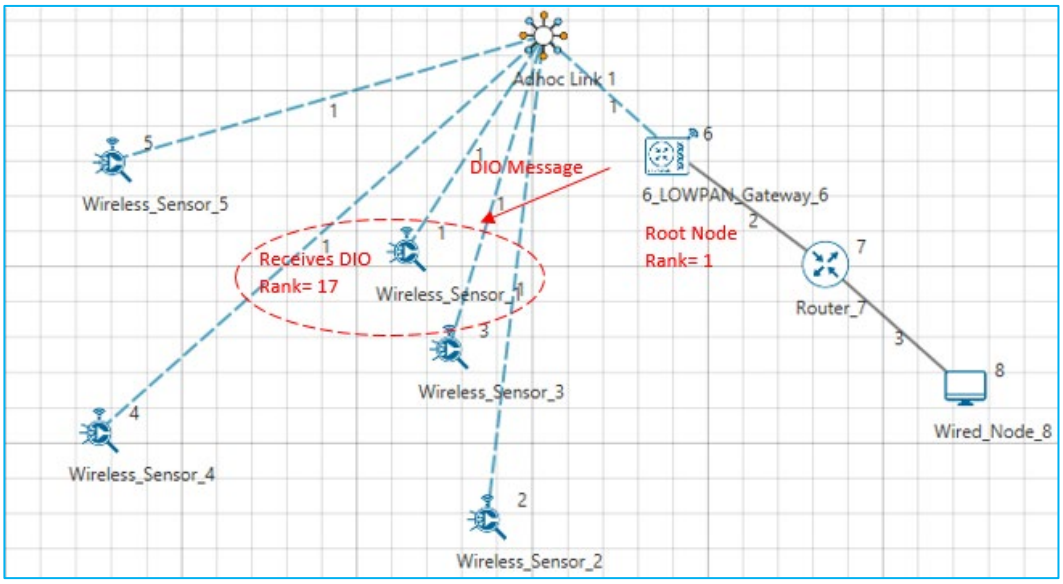


Figure 3-6: Node 1 choses its “Parent as Node 6 - New Rank = 17

Step 3:

- Node 6 receives as DAO message from Node 1 with the new route information about the destination and the Gateway.

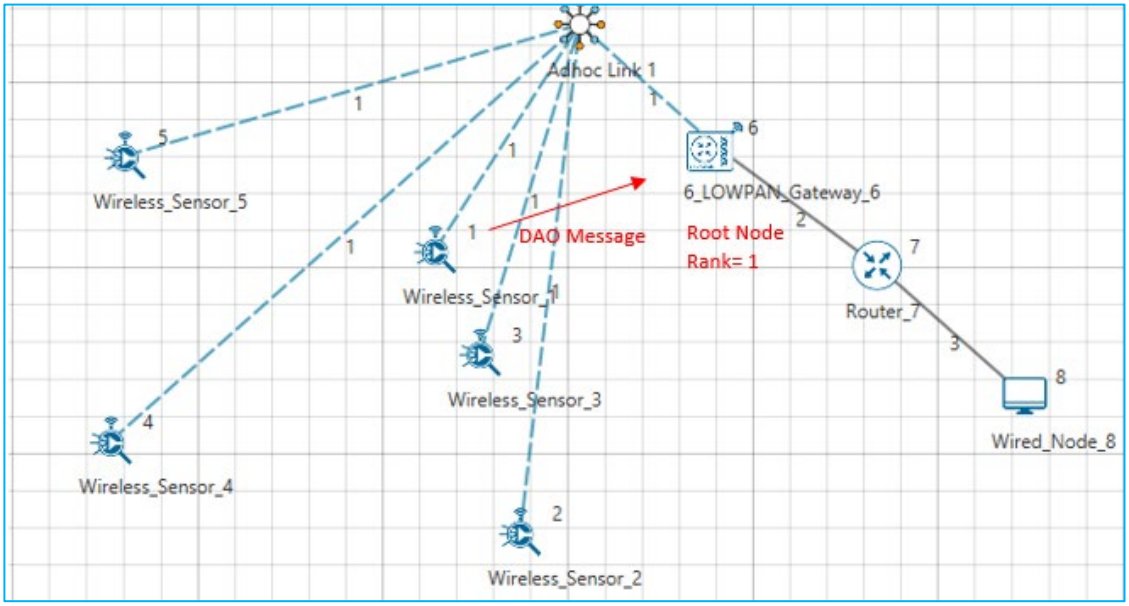


Figure 3-7: Node 6 receives as DAO message from Node 1

Step 4:

- Node 2 receives a DIO msg from Node 1 (i.e. Sensor which is configured as Router).
- Node 2 finds the DODAG id

- Based on the DIO message received from Node 1, Node 2 choses its “Parent as Node 1” and establishes its “New Rank = 33” since it is in the next Rank level. It doesn’t have any siblings.

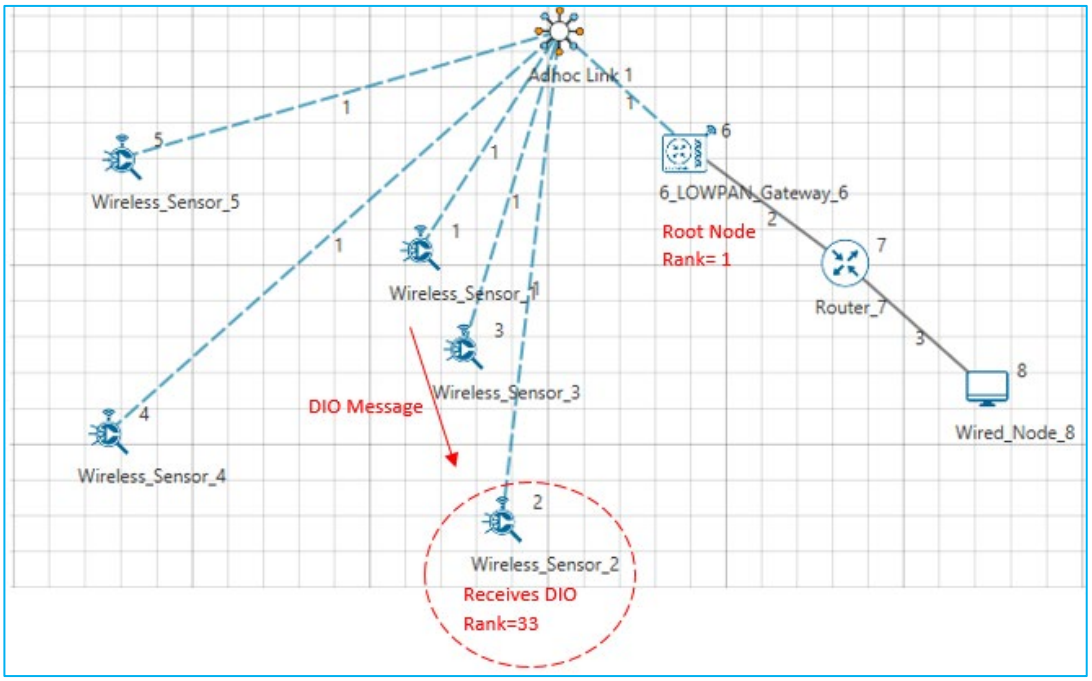


Figure 3-8: Node 2 choses its “Parent as Node 6 - New Rank = 33

Likewise, DODAG formation throughout the simulation is logged inside the rpl_log file

3.2.4 Viewing RPL control messages in Wireshark

Wireshark option can be enabled in the ZigBee devices to capture network traffic during the simulation. RPL control messages such as DAO, DIO etc can be seen in Wireshark as shown below **Figure 3-9.**

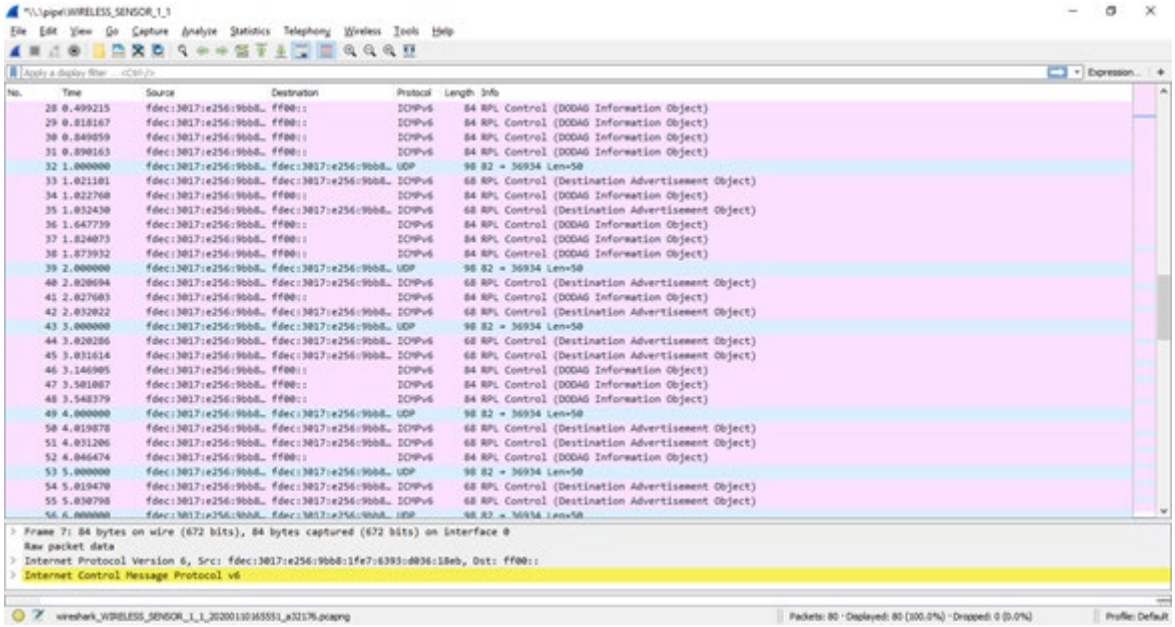


Figure 3-9: Wireshark captures RPL control messages such as DAO, DIO etc

Following is a screenshot of a DIO message where the Rank information is highlighted as shown **Figure 3-10.**

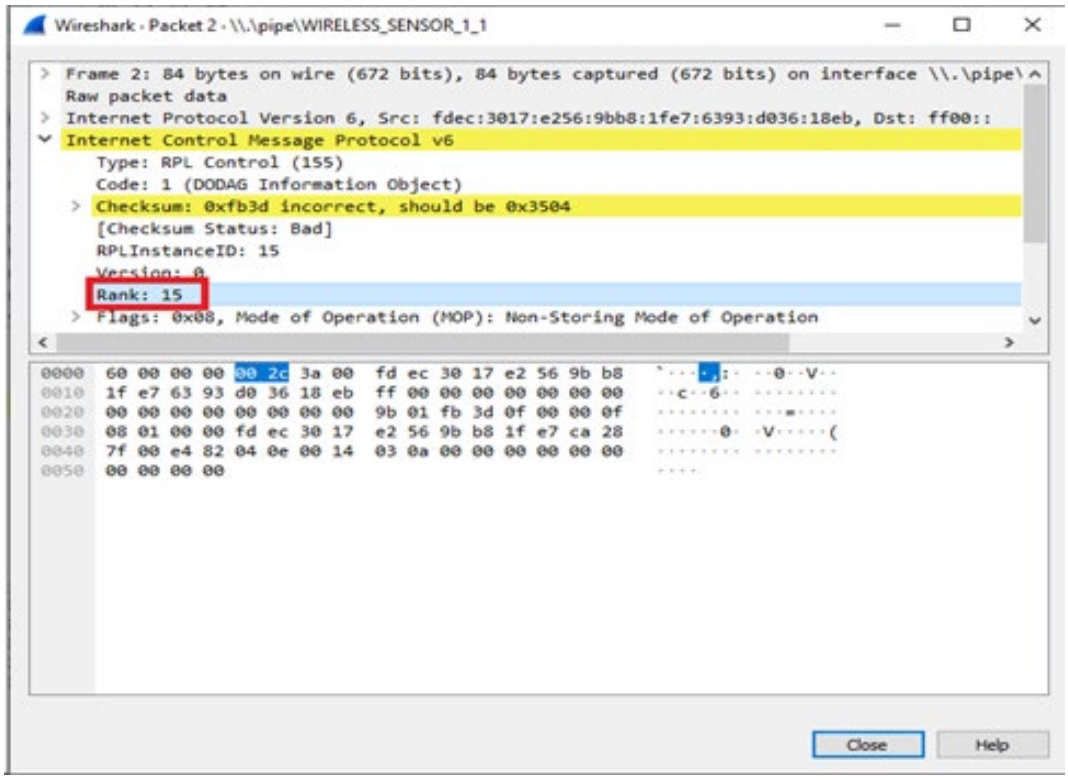


Figure 3-10: DIO message with Rank information in wireshark

3.3 MAC / PHY: 802.15.4 Overview

IEEE802.15/TG4 formulated the IEEE802.15.4 for low-rate wireless personal area network, i.e. LR-WPAN. The standard gives priority to low-power, low-rate and low-cost. The group devotes to the standard of the physical layer of WPAN network, i.e. PHY, and media access layer.

The WSN part of the IOT Network runs 802.15.4 in MAC and PHY. The features implemented are:

Superframe

- Beacon enabled and beacon disabled mode.
- In beacon enabled mode NetSim supports slotted CSMA/CA with Active & Inactive Period (controlled by Beacon order and super-frame order parameters)
- GTS is not implemented.

Data Transfer Model

- Device to co-ordinator, Co-ordinator to device and Device to device (peer to peer topology)

- AckRequestFlag - If set the device acknowledges successful reception of the data frame by transmitting an ack frame.

Frames

- Beacon
- Data
- Acknowledgement

CSMA / CA Mechanism

- Non-beacon mode uses unslotted CSMA/CA.
- Beacon mode uses slotted CSMA/CA.

Power Model

- Power source:
- Main Line
- Battery model which logs Initial energy, consumed energy and remaining energy.
- Energy Harvesting
- Consumption Modes
    - Transmit
    - Receive
    - Idle
    - Sleep

3.3.1 CSMA/CA Implementation in NetSim

- In both Slotted and Unslotted CSMA/CA cases, the CSMA/CA algorithm is based on backoff periods, where one backoff period is equal to aUnitBackoffPeriod Symbols = 20 symbols.
- This is the basic time unit of the MAC protocol and the access to the channel can only occur at the boundary of the backoff periods. In slotted CSMA/CA the backoff period boundaries must be aligned with the superframe slot boundaries where in unslotted CSMA/CA the backoff periods of one device are completely independent of the backoff periods of any other device in a PAN.
- The CSMA/CA mechanism uses three variables to schedule the access to the medium:
- NB is the number of times the CSMA/CA algorithm was required to backoff while attempting the access to the current channel. This value is initialized to zero before each new transmission attempt.
- CW is the contention windows length, which defines the number of backoff periods that need to be clear of channel activity before starting transmission. CW is only used with

the slotted CSMA/CA. This value is initialized to 2 before each transmission attempt and reset to 2 each time the channel is assessed to be busy.

- BE is the backoff exponent, which is related to how many backoff period a device must wait before attempting to assess the channel activity.
- In beacon-enabled mode, each node employs two system parameters: **beacon order (BO) and Superframe Order (SO)**.
- The parameter BO decides the length of beacon interval (BI), where **BI =** *aBaseSuperframeDuration* **× 2^{BO} symbols** and $0 \le BO \le 14$; while the parameter SO decides the length of superframe duration (SD), where **SD =** *aBaseSuperframeDuration* **× 2^{SO} symbols** and $0 \le SO \le BO \le 14$.
- The value of *aBaseSuperframeDuration* is fixed to 960 symbols. The format of the superframe is defined as shown in the following figure:

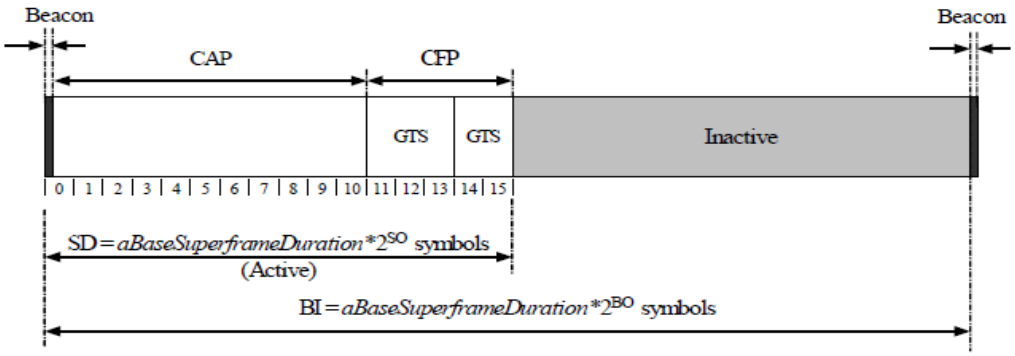


Figure 3-11: The format of the superframe structure

- Furthermore, the active portion of each superframe consists of three parts: beacon, CAP, and CFP, which is divided into 16 equal length slots. The length of one slot is equal to *aBaseSlotDuration* × 2^{SO} symbols, where *aBaseSlotDuration* is equal to 60 symbols.
- In CAP, each node performs the CSMA/CA algorithm before transmitting data packet or control frame. Each node maintains three parameters: the number of backoffs (NB), contention window (CW), and backoff exponent (BE).
- The initial values of NB, CW, and BE are equal to 0, 2, and *Min Backoff Expo*, respectively, where *Min Backoff Expo* is by default 3 and it can be set upto 8.
- For every backoff period, node takes a delay for random backoff between 0 and 2^{BE}-1 Unit backoff Time (UBT), where UBT is equal to 20 symbols (or 80 bits).
- A node performs clear channel assessment (CCA) to make sure whether the channel is idle or busy, when the number of random backoff periods is decreased to 0.

- The value of CW will be decreased by one if the channel is idle; and the second CCA will be performed if the value of CW is not equal to 0. If the value of CW is equal to 0, it means that the channel is idle; then the node starts data transmission.
- However, if the CCA is busy, the value of CW will be reset to 2; the value of NB is increased by 1; and the value of BE is increased by 1 up to the maximum BE (*Max Backoff Expo*), where the value *Max Backoff Expo* is by default 5 and can be upto 8.
- The node will repeatedly take random delay if the value of NB is less than the value of Max CSMA BO (*macMaxCSMABackoff),* where the value of Max CSMA BO is equal to 4; and the transmission attempt fails if the value of NB is greater than the value of Max CSMA BO.

3.3.2 Beacon Order and Super Framer Order

Beacon frame is one of the management frames in IEEE 802.15.4 based WSNs and contains all the information about the network. A coordinator in a PAN can optionally bound its channel time using a SuperFrame structure which is bound by beacon frames and can have an active portion and an inactive portion. The coordinator enters a low-power (sleep) mode during the inactive portion.

The structure of this SuperFrame is described by the values of macBeaconOrder and macSuperframeOrder. The MAC PIB attribute macBeaconOrder, describes the interval at which the coordinator shall transmit its beacon frames. The value of macBeaconOrder, BO, and the beacon interval, BI, are related as follows:

For $0 \leq BO \leq 14$, BI = aBaseSuperframeDuration * 2^{BO} symbols

If BO = 15, the coordinator shall not transmit beacon frames except when requested to do so, such as on receipt of a beacon request command. The value of macSuperframeOrder, SO shall be ignored if BO = 15.

If SuperFrame Order (SO) is same as Beacon Order (BO) then there will be no inactive period and the entire SuperFrame can be used for packet transmissions. If BO=10, SO=9 half of the SuperFrame is inactive and so only half of SuperFrame duration is available for packet transmission. If BO=10, SO=8 then $(3/4)^{th}$ of the SuperFrame is inactive and so nodes have only $(1/4)^{th}$ of the SuperFrame time for transmitting packets

3.4 Battery/Energy Model

NetSim has a dedicated power model for Sensor nodes that are part of WSN/IoT networks. The power model is user configurable and can be found in the ZigBee Interface properties of the Sensor nodes as shown below **Figure 3-12.** The default settings are as per Reference document [1].

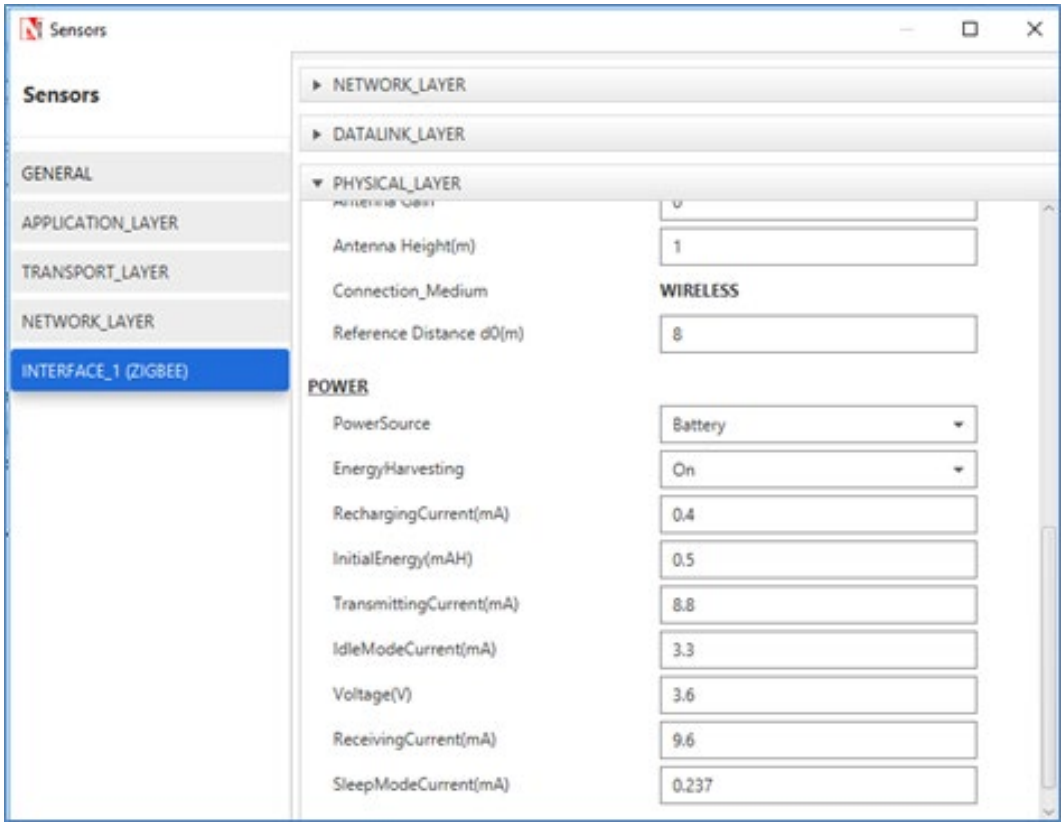
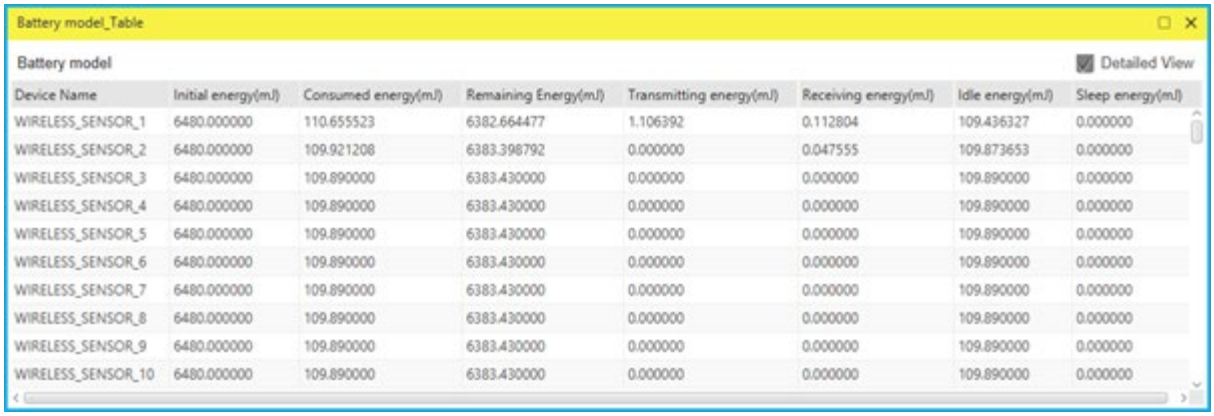


Figure 3-12: Network layer properties window

Energy consumption is calculated individually for each Sensor node that is part of the network scenario during various Radio States such as SLEEP, TRX_ON_BUSY, RX_ON_IDLE, RX_ON_BUSY, RX_OFF. Based on the calculations done, NetSim provides a detailed Energy Metrics table which provides energy consumption of each device with respect to Transmission, Reception, Idle Mode, and Sleep Mode as shown below **Figure 3-13.**



Device Name	Initial energy(mJ)	Consumed energy(mJ)	Remaining Energy(mJ)	Transmitting energy(mJ)	Receiving energy(mJ)	Idle energy(mJ)	Sleep energy(mJ)
WIRELESS_SENSOR_1	6480.000000	110.655523	6382.664477	1.106392	0.112804	109.436327	0.000000
WIRELESS_SENSOR_2	6480.000000	109.921208	6383.398792	0.000000	0.047555	109.873653	0.000000
WIRELESS_SENSOR_3	6480.000000	109.890000	6383.430000	0.000000	0.000000	109.890000	0.000000
WIRELESS_SENSOR_4	6480.000000	109.890000	6383.430000	0.000000	0.000000	109.890000	0.000000
WIRELESS_SENSOR_5	6480.000000	109.890000	6383.430000	0.000000	0.000000	109.890000	0.000000
WIRELESS_SENSOR_6	6480.000000	109.890000	6383.430000	0.000000	0.000000	109.890000	0.000000
WIRELESS_SENSOR_7	6480.000000	109.890000	6383.430000	0.000000	0.000000	109.890000	0.000000
WIRELESS_SENSOR_8	6480.000000	109.890000	6383.430000	0.000000	0.000000	109.890000	0.000000
WIRELESS_SENSOR_9	6480.000000	109.890000	6383.430000	0.000000	0.000000	109.890000	0.000000
WIRELESS_SENSOR_10	6480.000000	109.890000	6383.430000	0.000000	0.000000	109.890000	0.000000

Figure 3-13: Battery model Table in result window

3.5 Sensor Application - How to model sensing interval?

Agents and sensing range were used in earlier versions (before v11) of NetSim as an abstraction of physical phenomenon to trigger packet generation in the sensor nodes

respectively. Sensor nodes generate packets whenever they sense an agent within the sensor range. From NetSim v11 onwards users have the facility to configure traffic in the sensor network using the application as shown **Figure 3-14.**

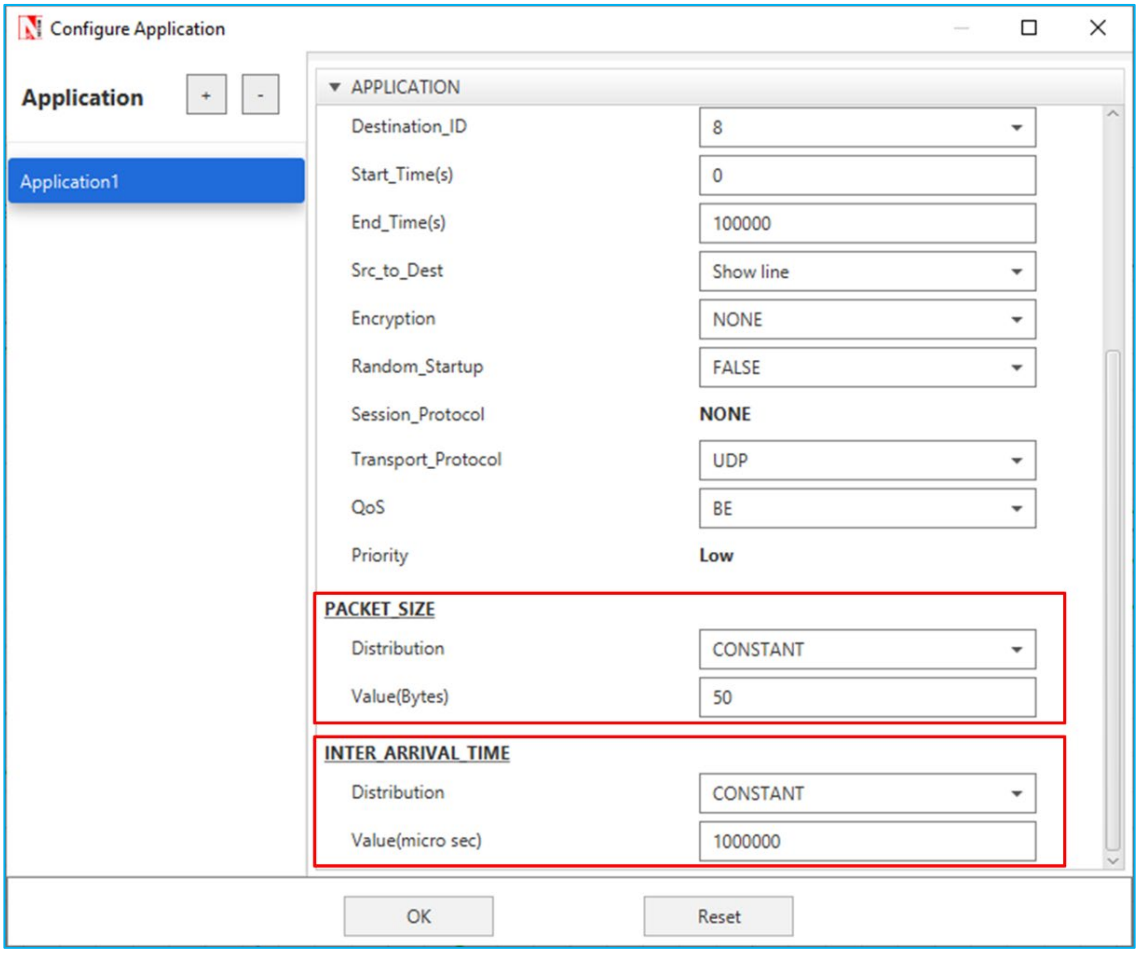


Figure 3-14: Application window

In the application properties, the size of the packet can be set under packet size and the Inter-arrival time can be thought of as sensor interval.

Users can now configure traffic between sensor and sink node as well as between the sensor nodes.

Note that Agents, sensor interval, sensor range are deprecated in NetSim v11.

3.6 Model Limitations

- NetSim currently supports only single root in RPL.
- NetSim GUI supports only one RPL instance. Multiple RPL instance can be created by manually editing the config file.
- Security in 802.15.4 is not implemented.

3.7 WSN/IOT File Based Placement

File based placement, as the name suggests is an option that can be used to place devices in user defined locations based on the text file which is provided as the input.

Why do we need File Based Placement?

- File Based Placement gives completely a user-defined approach for device placements during the process of Network design.
- This feature allows the user to design a large network scenario comprising of various devices with ease.
- It allows device placements with precision and so on.

Create a text file as per the following or use the file present in the Docs folder of NetSim Install Directory < C:\Program Files\NetSim Standard\Docs\Sample_Configuration\IOT>

3.7.1 Internet of Things

The text file that we give as an input can be saved as follows: **IOT_File_Based_Placement.txt**

The general format to be followed while creating an IOT_File_Based_Placement.txt for all the devices used in it is given below:

<DEVICE_NAME>,<DEVICE_TYPE>,<X>,<Y>

where,

DEVICE_NAME represents the name of the device and can be user defined.

DEVICE_TYPE represents the type of device and this info can be obtained from the "General Properties" of that particular device.

X represents the X_Coordinate position of the device upon the grid.

Y represents the Y_Coordinate position of the device upon the grid.

Note: *Once after we give a file-based input for device placement, an ad-hoc link will automatically be established connecting all the devices pertaining to it. And users need to manually connect the remaining devices using the Wired/Wireless links.*

Must the IOT text file contain only IOT devices?

The IOT txt file can include all the devices that are present in the top ribbon/toolbar when we select Internet of Things from the home screen. This varies based on the network type. For e.g. WSN and MANETs network types support different devices comparatively.

IOT_File_based_placement.txt

Wireless_Sensor,IOT_Sensors,0,0

Wireless_Sensor,IOT_Sensors,10,10

Wireless_Sensor,IOT_Sensors,20,20

Wireless_Sensor,IOT_Sensors,30,30

Wireless_Sensor,IOT_Sensors,40,20

Low_Pan_Gateway,LOWPAN_Gateway,50,10

Router,IOT_ROUTER,60,20

Wired_Node,WIREDNODE,70,20

Open NetSim and click **New Simulation → Internet Of Things.** In the Fast Config window, Choose the **File Based Placement** option under Automatic Placement and give the path of the text file as shown belo**w Figure 3-15.**

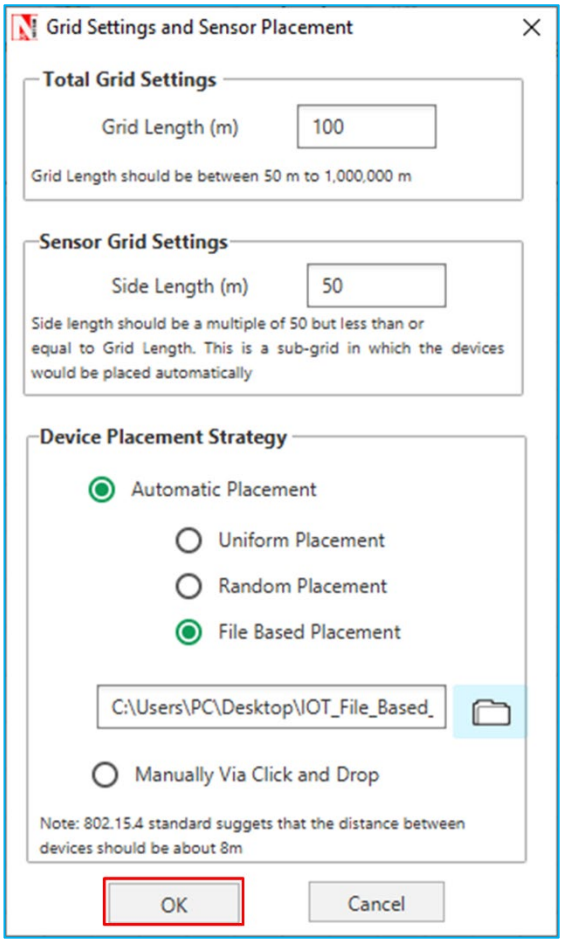


Figure 3-15: Device placement Strategy to File based Placement in IOT

After giving the path, Click on OK. It will display the IOT network as shown below, where all devices are placed as per the positions given in the text file.

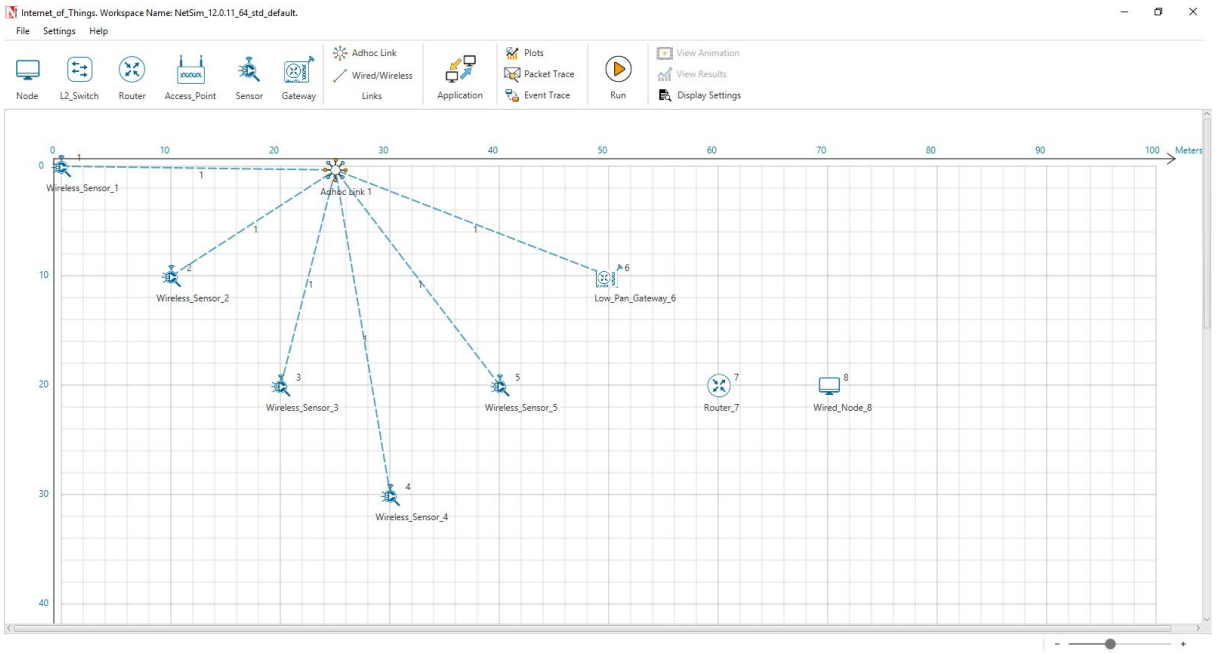


Figure 3-16: Network Topology in IOT

Connect Low_Pan_Gateway to Router and Router to Wired node. Configure application and run simulation.

3.7.2 Wireless Sensor Networks

Create a text file as per the following or use the file present in the Docs folder of NetSim Install Directory < C:\Program Files\NetSim Standard\Docs\Sample_Configuration\WSN>

WSN_File_based_placement.txt

Wireless_Sensor,Sensors,5,5

Wireless_Sensor,Sensors,10,10

Wireless_Sensor,Sensors,20,10

Wireless_Sensor,Sensors,5,10

WSN_Sink,SinkNode,10,15

Open NetSim and click **New Simulation → Wireless Sensor Networks.** Select **File Based Placement** option under Automatic Placement and give the path of the text file as shown below **Figure 3-17.**

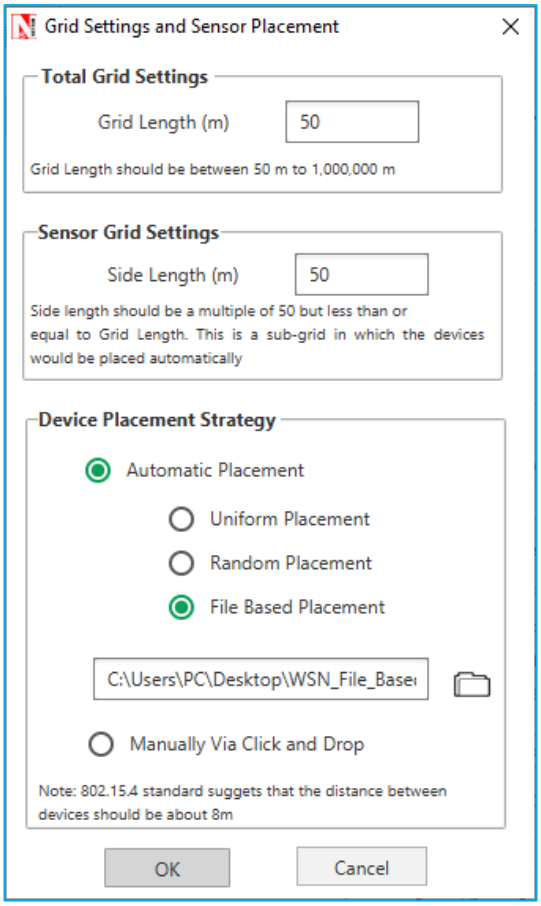


Figure 3-17: Device placement Strategy to File based Placement in WSN

After giving the path, Click on OK. It will display the WSN network as shown below, where all devices are placed as per the positions given in the text file.

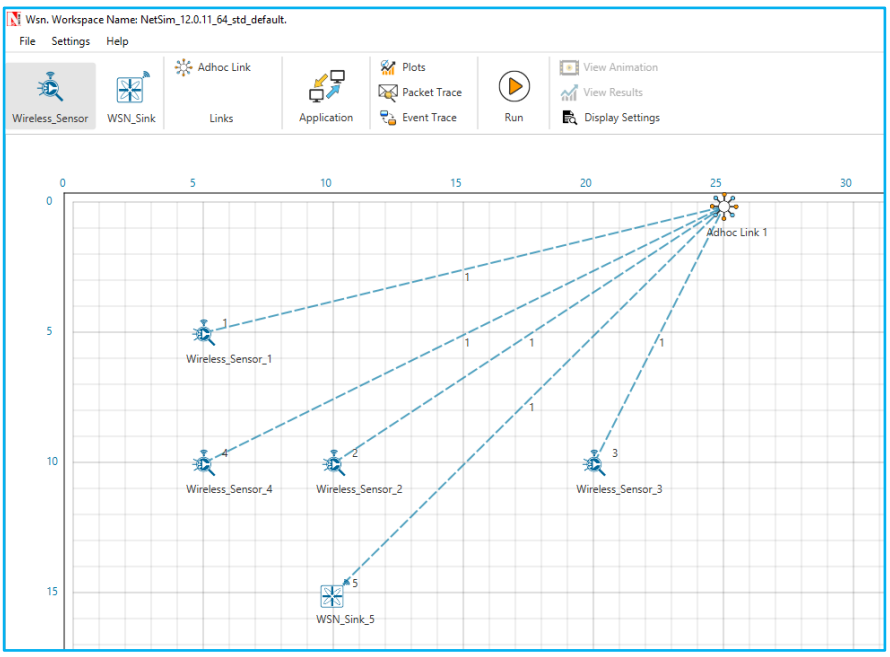


Figure 3-18: Network Topology in WSN

Note: *Please refer section "2.1 Fast configuration" for more information.*

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 IOT Example Simulations

4.1.1 Energy Model

Open NetSim, Select **Examples->IOT-WSN->Internet-of-Things->Energy-Model** as shown **Figure 4-1.**

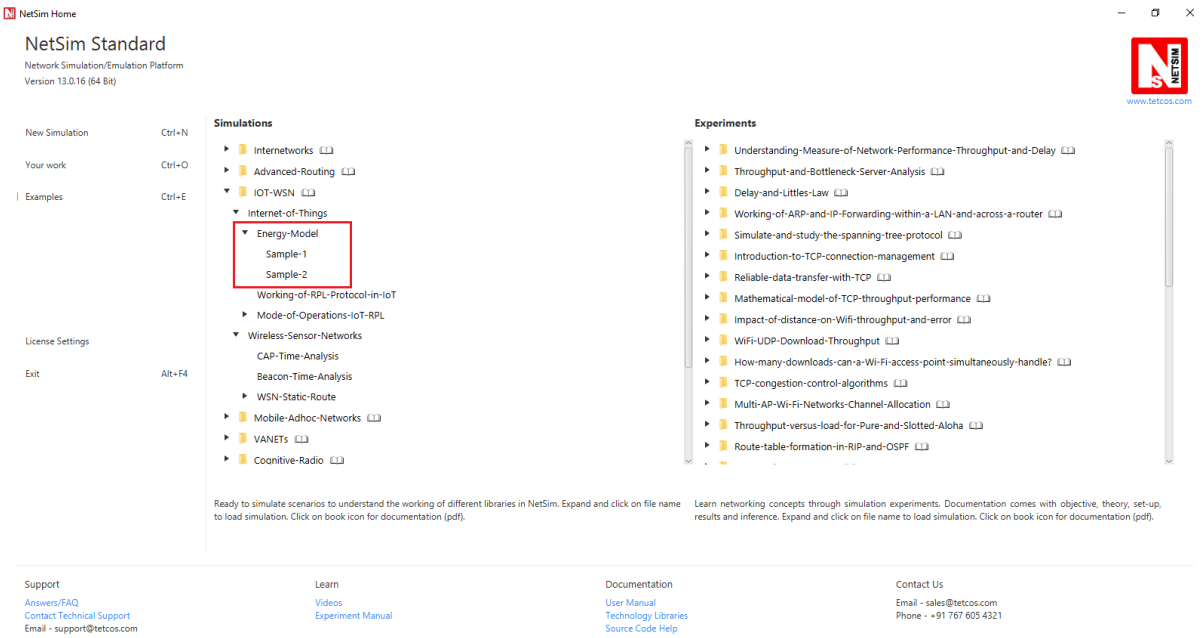


Figure 4-1: Featured Examples list

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

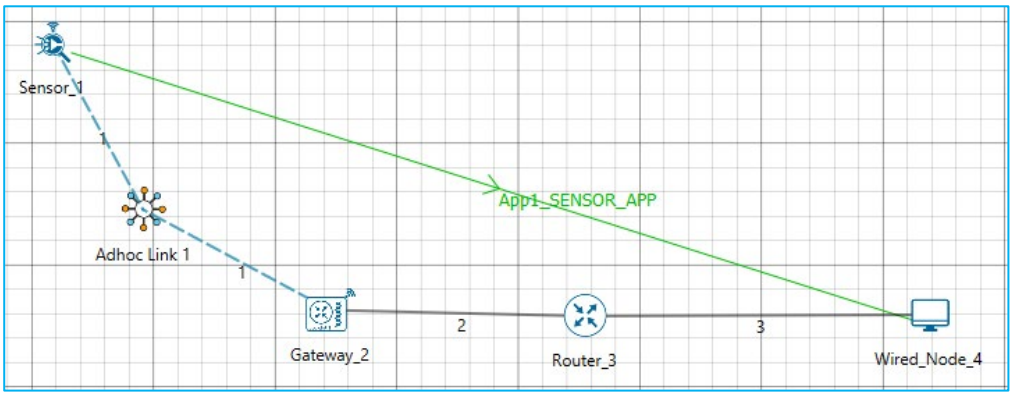


Figure 4-2: Network Topology

Settings done in sample network

1. Grid length(m) →100, Side Length(m) →100, Manually via Click and Drop.
2. In LOWPAN_Gateway change BeaconMode → Enable, Superframe Order → 10, Beacon Order →10.
3. Channel Characterstic → NO PATHLOSS in Adhoc link Properties.

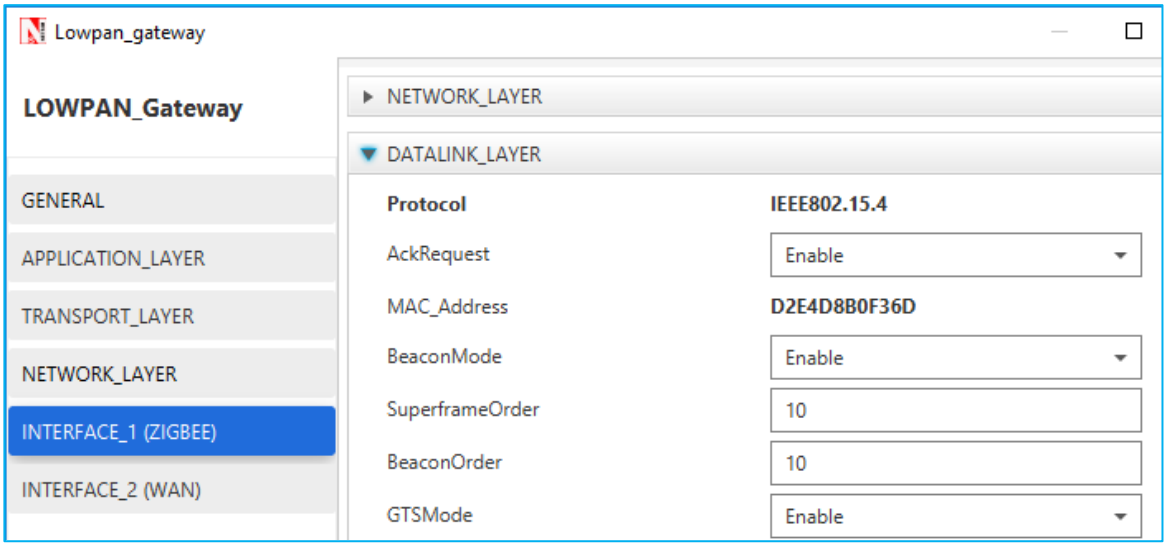


Figure 4-3: Datalink layer Properties for Lowpan Gateway

4. In NetSim GUI Plots are Enabled.
5. Run the simulate for 100 sec.
6. Check the Battery model in simulation results window, users should get zero value for Sleep energy (mJ) consumed.
7. Go back to Simulation window change following properties in LOWPAN_Gateway for another sample.
8. Set Superframe Order (SO) and Beacon Order (BO) as 10 and 12 respectively (0 <= SO <= BO <= 14)
9. Re-run the Simulate for 100 sec.
10. Check the Battery Model metrics in metrics window, users should get non-zero value for Sleep energy consumed.

Results: In sample 1, users can observe sleep energy consumed value will be zero in Battery Model metrics in the Results Window since sensor is in active state all the time. i.e., if SO=10 and BO=10, there won't be any inactive portion of the Superframe.

In sample 2, sleep energy consumed will be non-zero since sensor goes to sleep mode during the inactive portion of the Superframe.

4.1.2 Working of RPL Protocol in IoT

Open NetSim, Select **Examples->IOT-WSN->Internet-of-Things->Working-of-RPL-Protocol-in-IoT** as shown **Figure 4-4.**

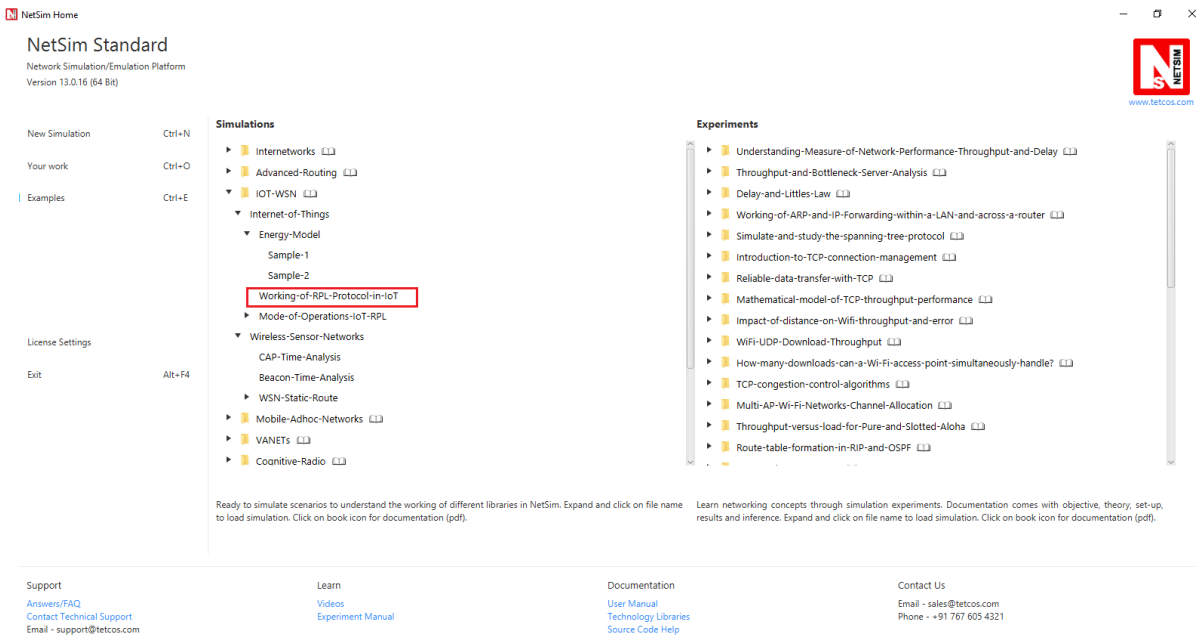


Figure 4-4: Featured Examples list

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

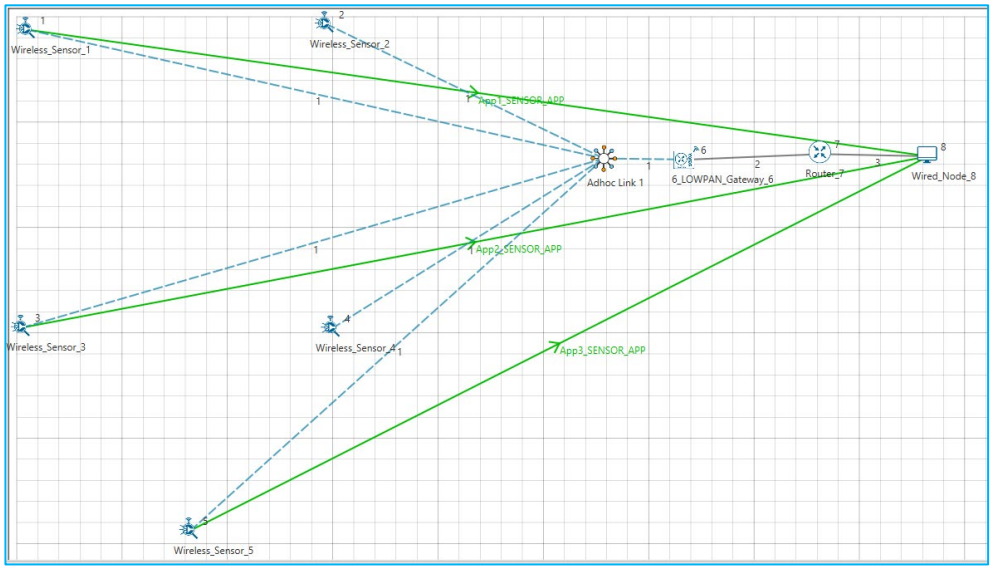


Figure 4-5: Network Topology

Settings done in sample network:

1. Grid length(m) → 100m, Side Length(m) → 50, Manually via Click and Drop.

2. Routing protocol has set as RPL for 6LOWPAN Gateway and Sensor. Go to properties → Network Layer → Routing Protocol as shown **Figure 4-6.**

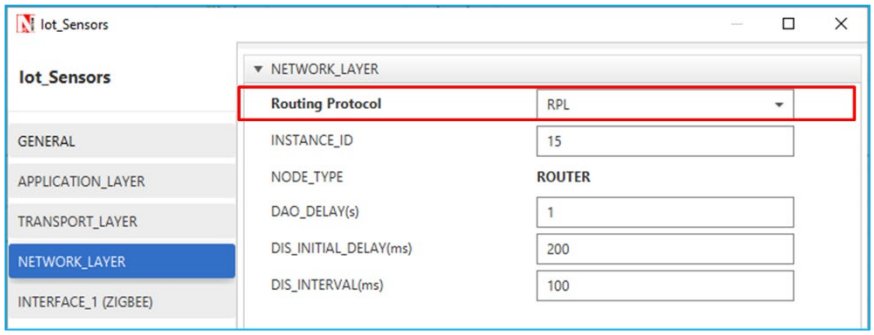


Figure 4-6: Routing Protocol to RPL in Network layer

3. In Adhoc Link Properties change Channel characteristics → Path Loss only, Path Loss Model → Log Distance and path loss exponent → 3.5
4. Application properties has set as shown in below table **Table 4-1.**

Application Properties			
Application ID	**Application Type**	**Source Id**	**Destination Id**
1	SENSOR_APP	1	8
2	SENSOR_APP	3	8
3	SENSOR_APP	5	8

Table 4-1: Application properties

Procedure to get detailed RPL log file:

- Go to NetSim Home page and click on **Your work**.
- Click on Workspace Options and then click on **Open Code** and open the codes in Visual Studio. Set **Win32** or **x64** according to the NetSim build which you are using.
- Go to the RPL Project in the Solution Explorer. Open RPL.h file and change //**#define DEBUG_RPL** to **#define DEBUG_RPL** as shown below **Figure 4-7.**

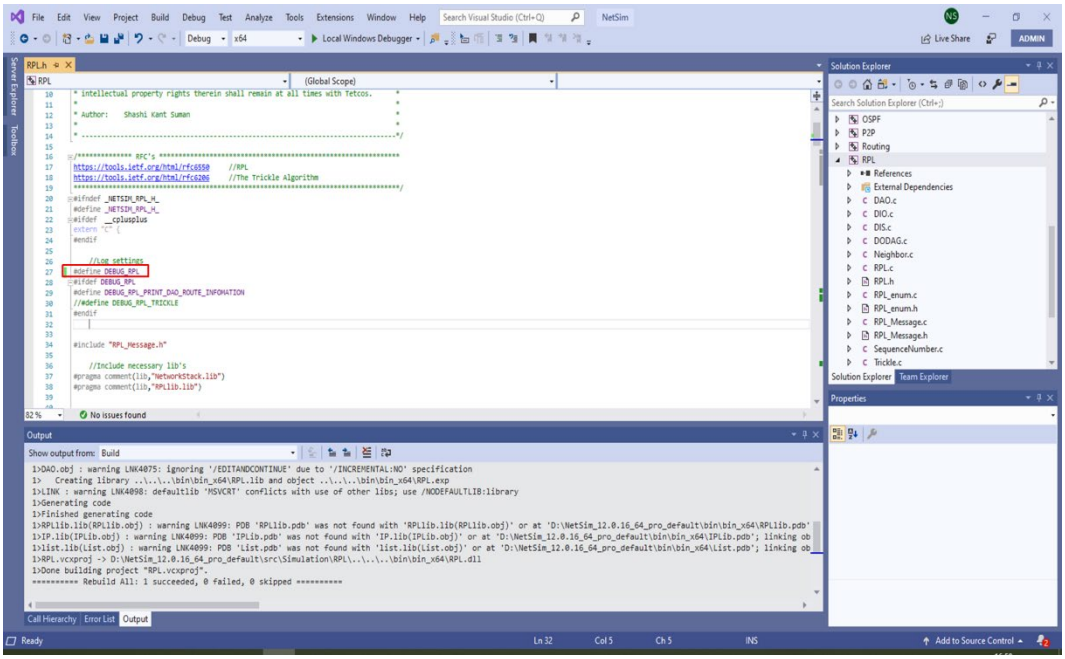


Figure 4-7: Visual Studio

- Right click on the **RPL** project in the solution explorer and click on rebuild.
- After the RPL project is rebuild successful, go back to the network scenario.

5. In NetSim GUI Plots are Enabled. Run simulation for 100 sec and go to Result window → Log Files, open rpl log file.

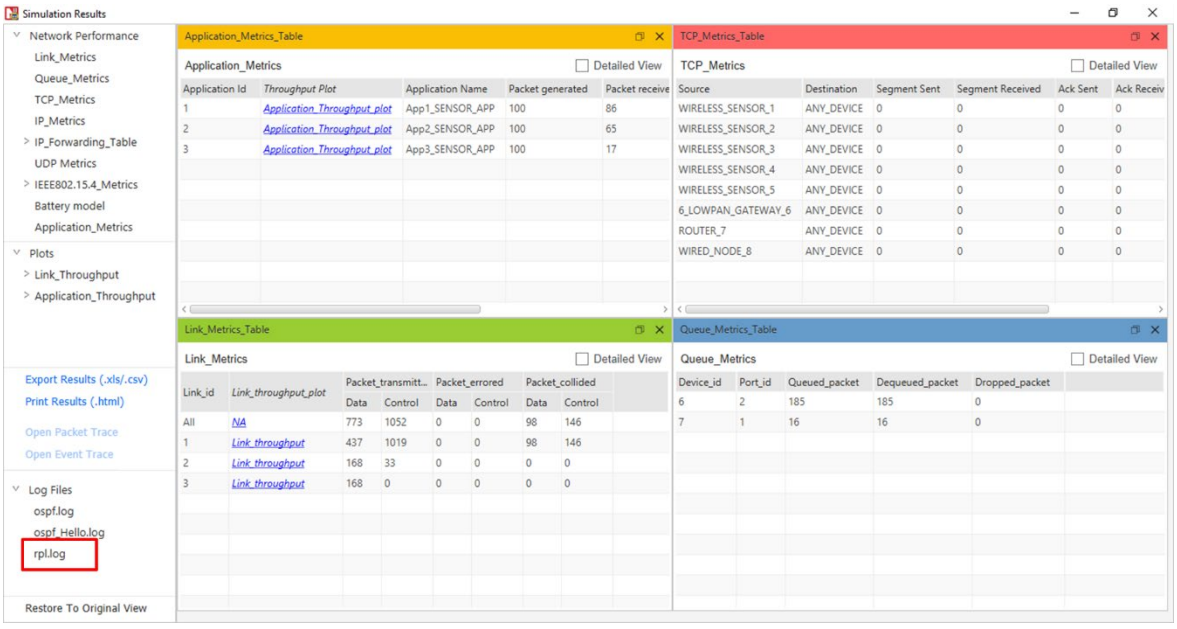


Figure 4-8: Simulation Result window

Results

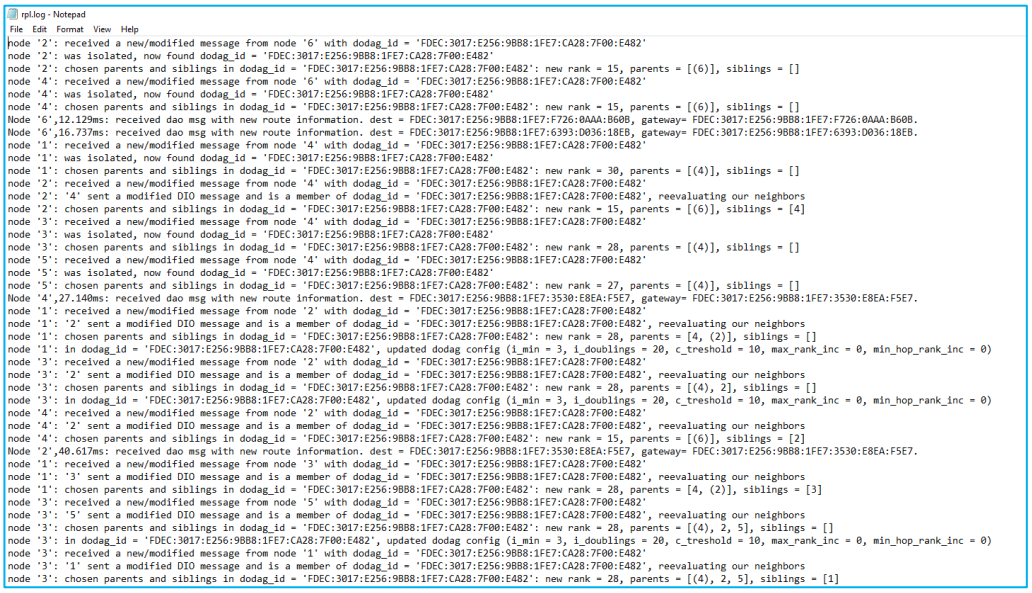


Figure 4-9: RPL log file

The observation of rpl log file which is generated in NetSim is given in the below **Table 4-2.**

Node	Rank	Updated Rank	Parent list	Updated Parent Node ID	Sibling Node ID	Received DIO From Node ID
Node 1	30	28	Node 2, Node 4	Node 2	Node 3	Node 2, Node 3, Node 4
Node 2	15	15	Node 6	Node 6	Node 4	Node 4, Node 6
Node 3	28	28	Node 2, Node 4, Node 5	Node 4	Node 1	Node 1, Node 2, Node 4, Node 5
Node 4	15	15	Node 6	Node 6	Node 2	Node 2, Node 6
Node 5	27	27	Node 4	Node 4	-	Node 4

Table 4-2: RPl Log file contains Rank, Updated Rank, Parent list, Updated Parent Node ID, Sibling Node ID and Received DIO From Node ID etc.

The above table can be summarised as follows:

DIO message is sent by the root node, i.e. LowPAN Gateway, with Rank 1 to Sensor 2 and Sensor 4 as shown **Figure 4-10.**

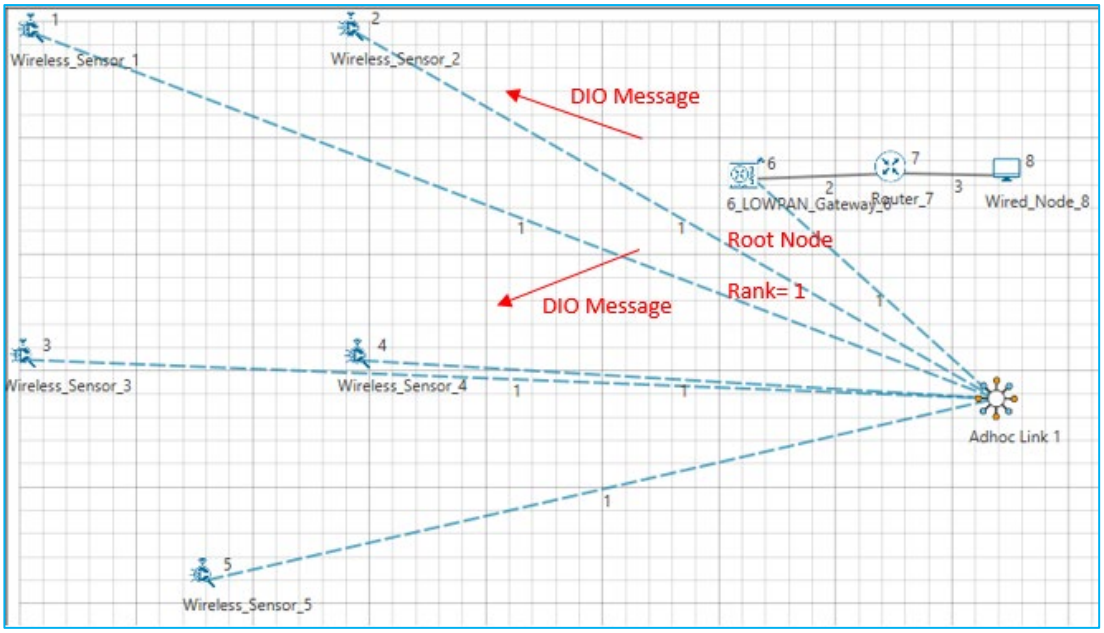


Figure 4-10: DIO messages sent by the LOWPAN Gateway to Sensors

On receiving the DIO message, Node 4 will recognize the DODAG Id of Root Node and identifies it as Parent node. Rank of Node 4 will get updated to 15. Also, Node 2 is recognized as sibling of Node 4.

Now, Node 4 will broadcast DIO message to other nodes as shown **Figure 4-11.**

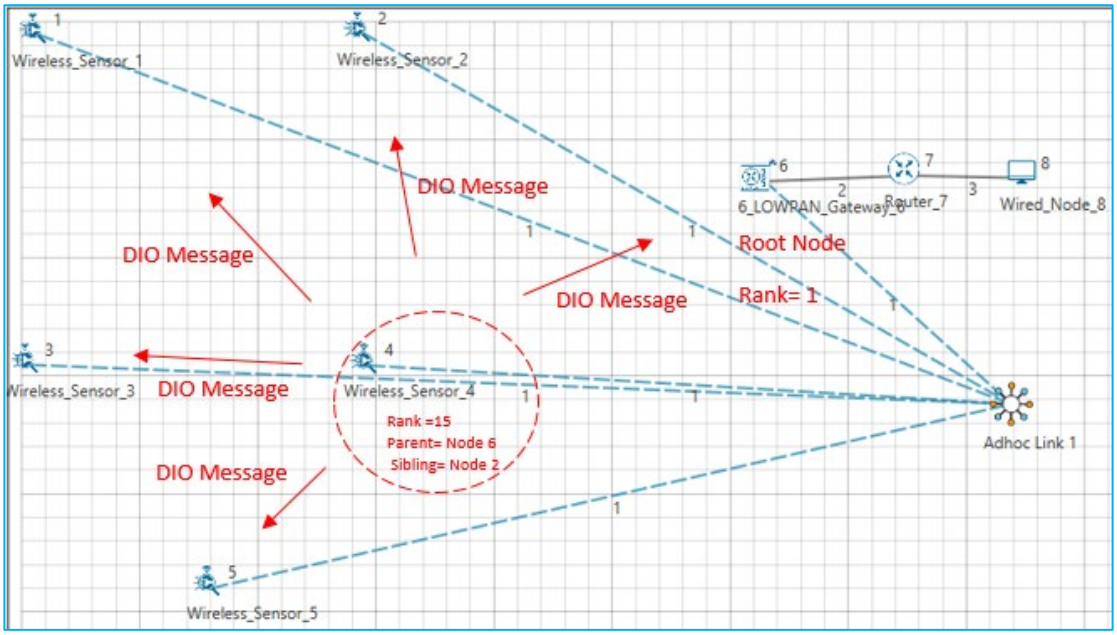


Figure 4-11: Wireless Seneor 4 broadcasting DIO message to other Sensors

Node 1 receives DIO message from Node 4 and it identifies the DODAG Id of Node 4. Hence, Node 1 recognizes Node 4 as the Parent Node. Rank of Node 1 will get updated to 30. As Node 3 is within the range of Node1, Node 3 is identified as a sibling of Node1.

Node 1 will then broadcast DIO messages as shown **Figure 4-12.**

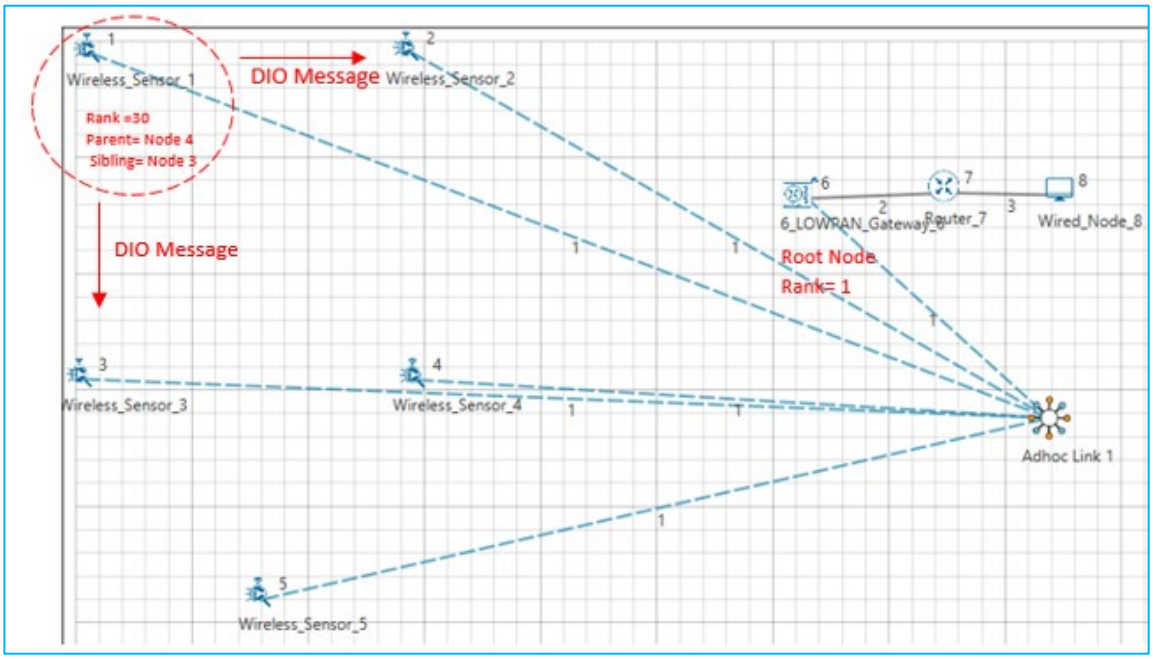


Figure 4-12: Wireless Seneor 1 broadcasting DIO message to other Sensors

Node 2 receives the DIO message from Node 6 and identifies it as Parent node. The Rank of Node 2 gets updated to 15. Node 2 now broadcasts the DIO message to other nodes as shown **Figure 4-13.**

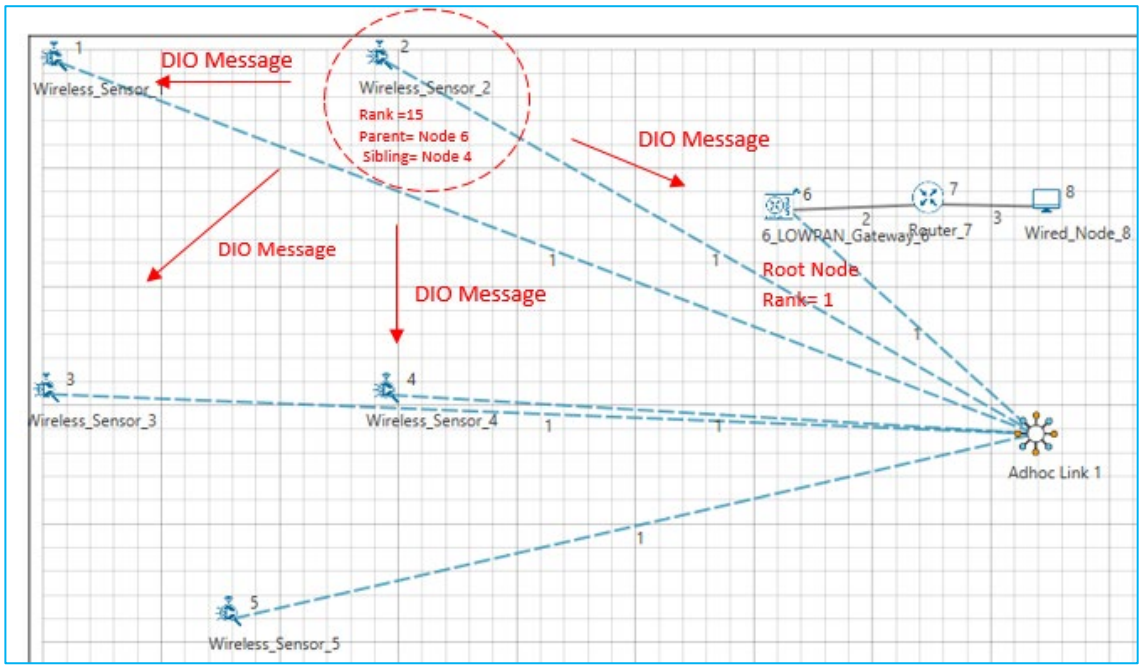


Figure 4-13: Wireless Seneor 2 broadcasting DIO message to other Sensors

Node 3 receives DIO message from Node 2 and the rank of Node 3 gets updated to 28. Node 2 is identified as the parent node of Node 3.

Node 3 then broadcasts DIO message to other nodes as shown **Figure 4-14.**

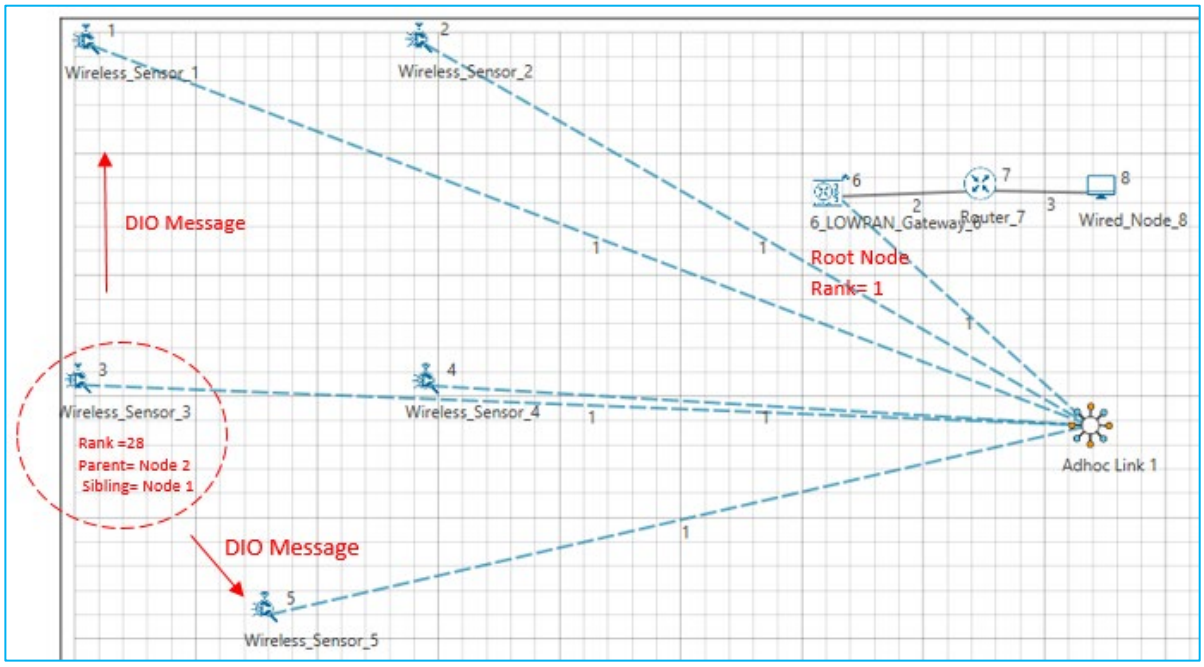


Figure 4-14: Wireless Seneor 3 broadcasting DIO message to other Sensors

Node 5 receives DIO message from Node 4, hence, it identifies Node 4 as th parent node. The rank of Node 5 gets updated to 27.

Node 5 then broadcasts DIO message as shown **Figure 4-15.**

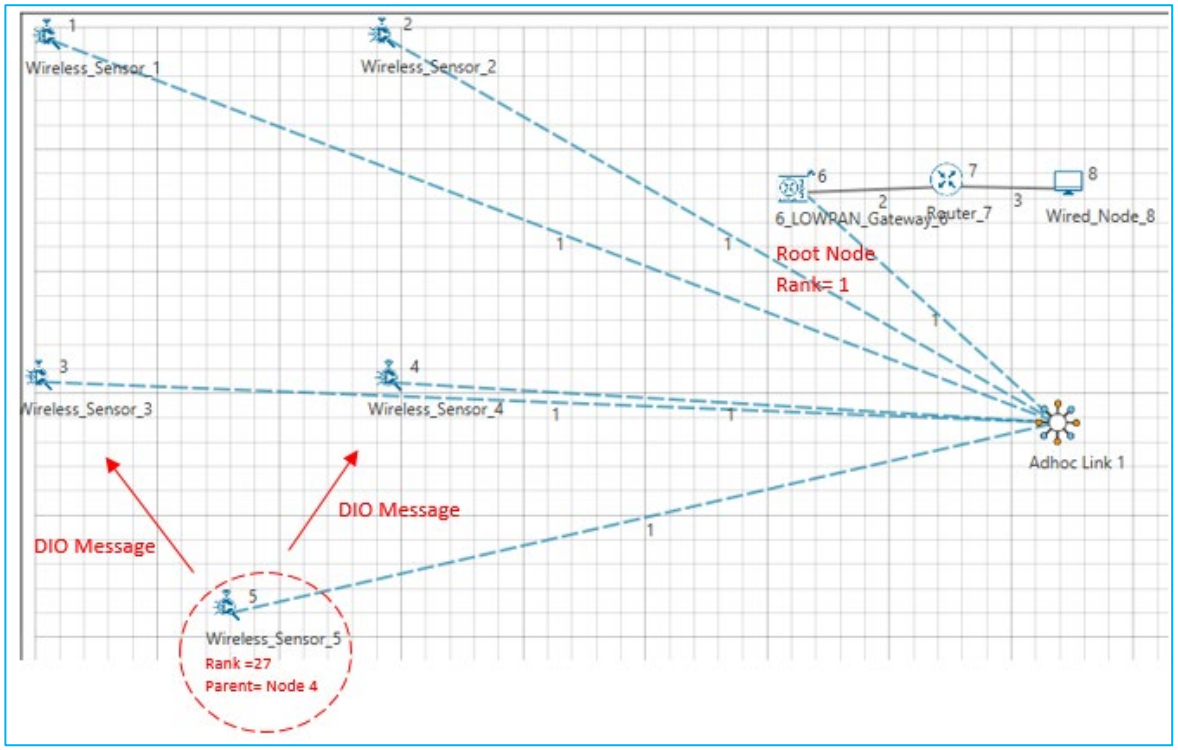


Figure 4-15: Wireless Seneor 5 broadcasting DIO message to other Sensors

Further, Node 1 receives DIO message from Node 2 and the parent list of Node 1 gets updated to Node 4 and Node 2. Also, the rank of Node 1 gets updated to 28.

According to the link quality, DODAG is formed.

- Node 2 and Node 4 are siblings and their parent is Node 6 (Root Node). Rank is 15.
- Node 1 and Node 3 are siblings.
    - Node 1 established its parent as Node 2. Rank is 28.
    - Node 3 establishes its parent as Node 4. Rank is 28
- Node 5 doesn't have any siblings and establishes its parent as Node 4. Its rank is 27.

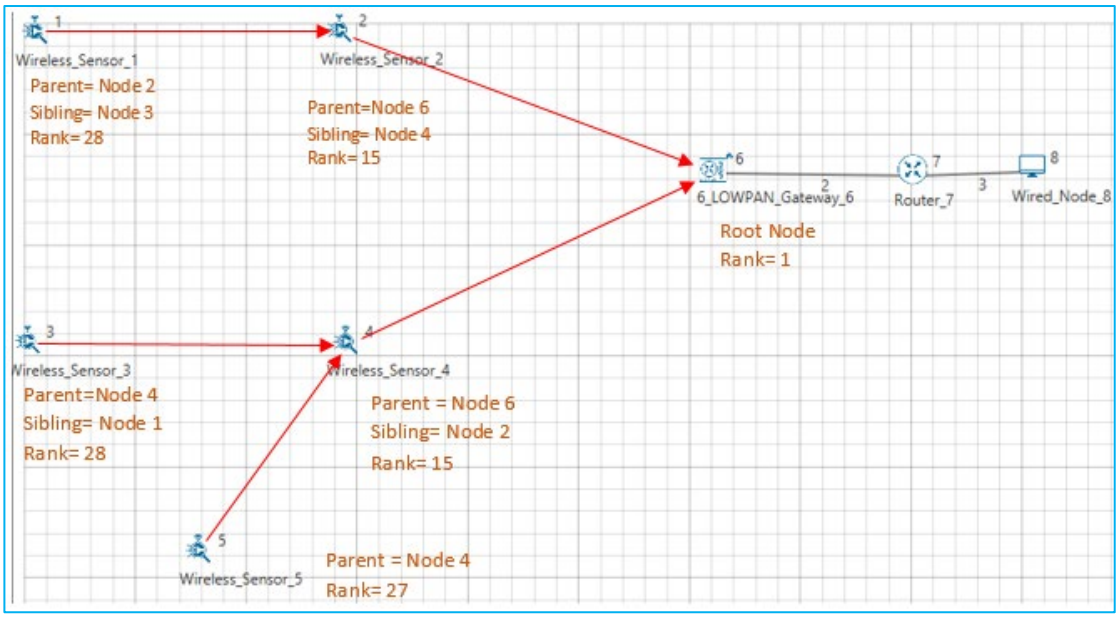


Figure 4-16: Based on link quality, DODAG is formed and Rank assiged to sensors and lowpan gateway

4.1.3 Mode of Operations in IoT RPL

The DODAG nodes process the DAO messages according to the RPL Mode of Operations (MOP), which are presented below. Independent of the MOP used, DAO messages may require reception confirmation, which should be done using DAO-ACK messages.

Although it is designed for the Multipoint-to-Point (MP2P) traffic pattern, RPL also admits the data forwarding using Point-to-Multipoint (P2MP) and Point-to-Point (P2P). In MP2P, the nodes send data messages to the root, creating an upward flow as shown in **Figure 4-17: Multipoint to Point**. In P2MP, sometimes termed as multicast, the root sends data messages to the other nodes, producing a downward flow depicted in **Figure 4-18: Point to Multipoint**.

In P2P, a node sends messages to the other node (non-root) of DODAG; thus, both upward and downward forwarding may be required as illustrated in **Figure 4-19: Point to Point.** RPL defines four MOPs that should be used considering the traffic pattern required by the

application and the computational capacity of the nodes. In the first, MOP 0 (Point to multipoint), RPL does not maintain downward routes; thus, consequently, only MP2P traffic is enabled. In non-storing MOP (MOP 1 (Multipoint to point)), downward routes are supported, and the use of P2P and MP2P is allowed. However, all downward routes are maintained in the root node. Thus, the total downward traffic should be initially sent to the DODAG root and subsequently be forwarded to its destination as shown in **Figure 4-20: RPL Non-Storing Mode**. In storing without multicast MOP (MOP 2 (Point to point)), downward routes are also supported, but are different from MOP 1; the nodes maintain, individually, a routing table constructed using DAO messages to provide downward traffic. Hence, downward forwarding occurs without the use of the root node, as illustrated in **Figure 4-21: RPL Storing Mode**. Storing with multicast MOP (MOP 3 (non-Storing mode)) has a functioning similar to MOP 2 (Point to point) plus the possibility of multicast data sending. This type of transmission permits the non-root node to send messages to a group of nodes formed using multicast DAOs.

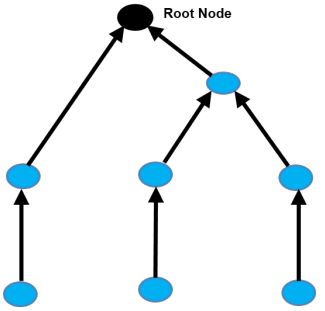


Figure 4-17: Multipoint to Point

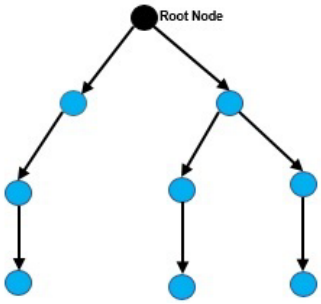


Figure 4-18: Point to Multipoint

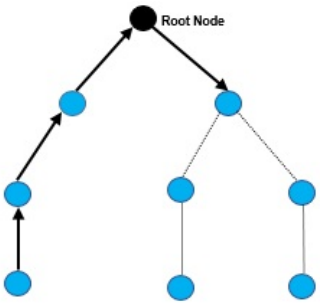


Figure 4-19: Point to Point

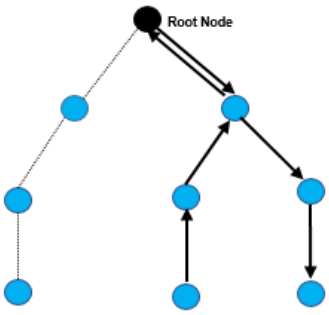


Figure 4-20: RPL Non-Storing Mode

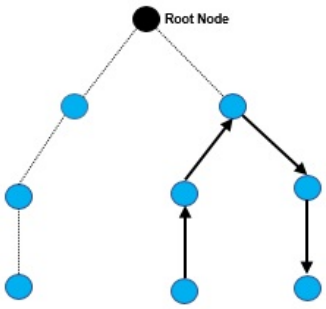


Figure 4-21: RPL Storing Mode

Open NetSim, Select **Examples->IOT-WSN->Internet-of-Things->Mode-of-Operations-IoT-RPL** as shown **Figure 4-22**.

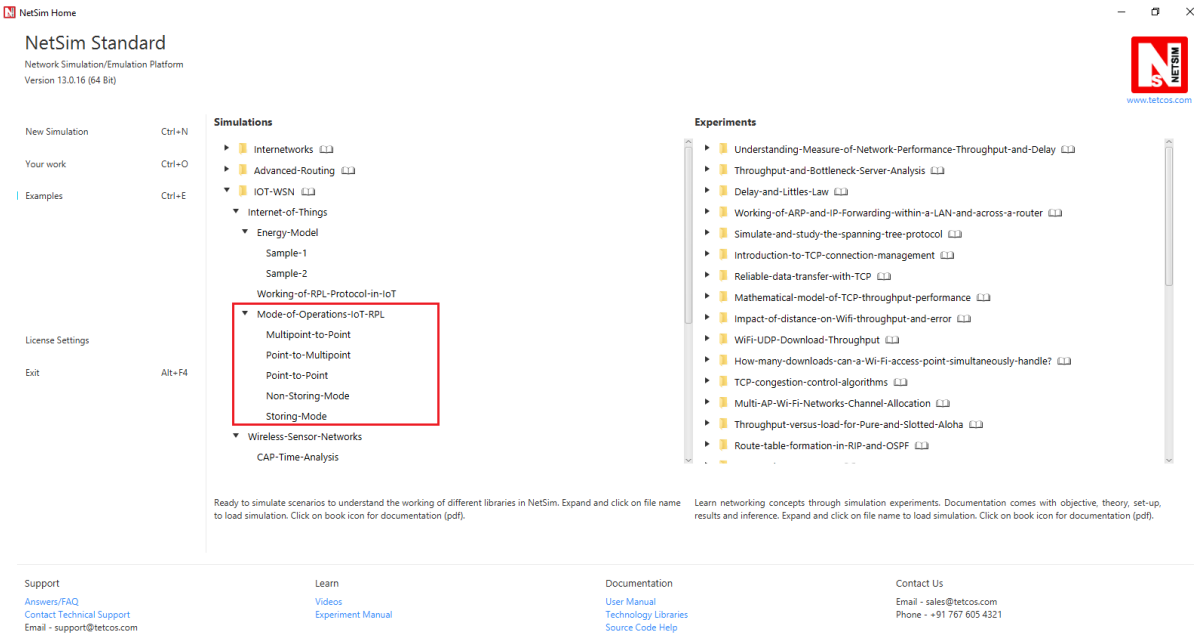


Figure 4-22: Featured Examples list

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

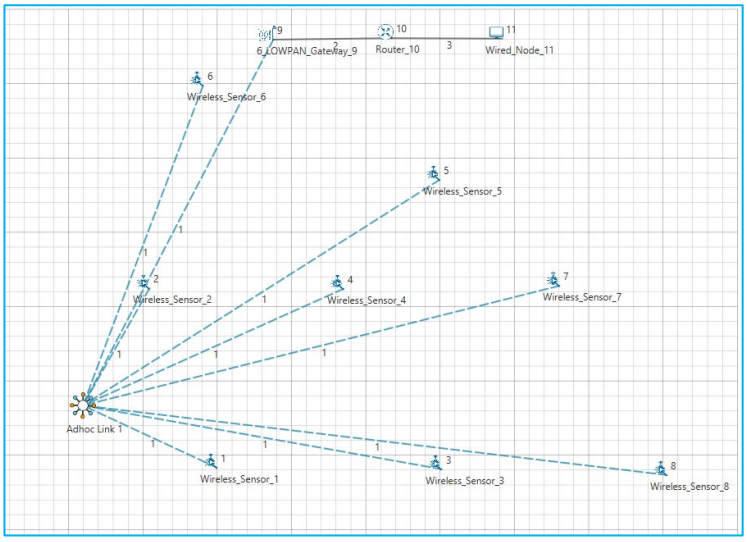


Figure 4-23: Network Topology in this experiment

4.1.3.1 Multipoint to Point

Settings done in sample network

1. Grid length(m) → 100m, manually via Click and Drop.
2. Routing protocol has set as RPL for 6LOWPAN Gateway and Sensor. Go to properties → Network Layer → Routing Protocol as shown **Figure 4-24.**

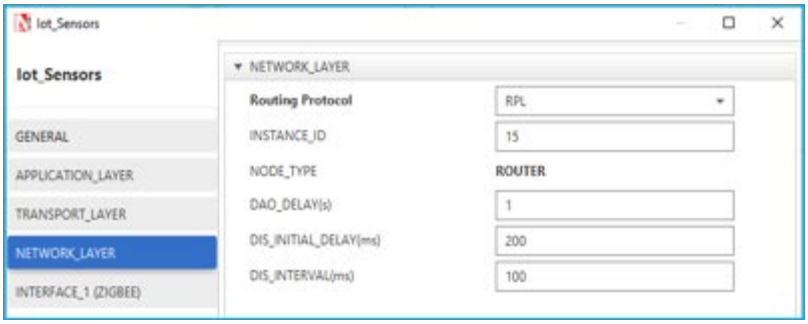


Figure 4-24: Routing Protocol to RPL in Network layer

3. In Adhoc Link Properties change Channel characteristics → Path Loss only, Path Loss Model → Log Distance and path loss exponent → 4.2
4. Application properties has set as shown in below **Table 4-3.**

Application Properties			
Application ID	**Application Type**	**Source Id**	**Destination Id**
1	SENSOR_APP	1	11
2	SENSOR_APP	3	11
3	SENSOR_APP	8	11

Table 4-3: Application properties

5. In NetSim GUI Plots are Enabled. Run simulation 100s and observe that all the sensors are sending data to route node in animation window and also in packet trace.

Result

Animation window: The nodes send data messages to the root, creating an upward flow,

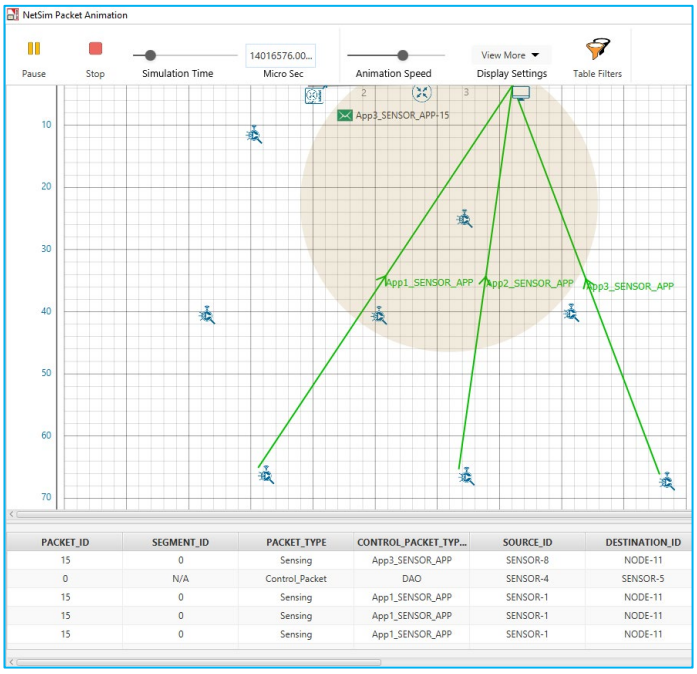


Figure 4-25: Animation window for Multipoint to Point

Packet trace

1	PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/APP_NAME	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID
224	2	0	Sensing	App1_SENSOR_APP	SENSOR-1	NODE-11	SENSOR-1	SENSOR-2
225	2	0	Sensing	App2_SENSOR_APP	SENSOR-3	NODE-11	SENSOR-3	SENSOR-4
226	2	0	Sensing	App3_SENSOR_APP	SENSOR-8	NODE-11	SENSOR-8	SENSOR-7
231	2	0	Sensing	App1_SENSOR_APP	SENSOR-1	NODE-11	SENSOR-2	SENSOR-6
232	2	0	Sensing	App1_SENSOR_APP	SENSOR-1	NODE-11	SENSOR-6	SINKNODE-9
233	2	0	Sensing	App1_SENSOR_APP	SENSOR-1	NODE-11	SINKNODE-9	ROUTER-10
234	2	0	Sensing	App1_SENSOR_APP	SENSOR-1	NODE-11	ROUTER-10	NODE-11
280	3	0	Sensing	App2_SENSOR_APP	SENSOR-3	NODE-11	SENSOR-3	SENSOR-4
281	3	0	Sensing	App1_SENSOR_APP	SENSOR-1	NODE-11	SENSOR-1	SENSOR-2
282	3	0	Sensing	App3_SENSOR_APP	SENSOR-8	NODE-11	SENSOR-8	SENSOR-7
283	3	0	Sensing	App1_SENSOR_APP	SENSOR-1	NODE-11	SENSOR-2	SENSOR-6
284	3	0	Sensing	App3_SENSOR_APP	SENSOR-8	NODE-11	SENSOR-7	SENSOR-5
290	3	0	Sensing	App1_SENSOR_APP	SENSOR-1	NODE-11	SENSOR-6	SINKNODE-9
291	3	0	Sensing	App1_SENSOR_APP	SENSOR-1	NODE-11	SINKNODE-9	ROUTER-10
292	3	0	Sensing	App1_SENSOR_APP	SENSOR-1	NODE-11	ROUTER-10	NODE-11
294	3	0	Sensing	App3_SENSOR_APP	SENSOR-8	NODE-11	SENSOR-5	SINKNODE-9
295	3	0	Sensing	App3_SENSOR_APP	SENSOR-8	NODE-11	SINKNODE-9	ROUTER-10
296	3	0	Sensing	App3_SENSOR_APP	SENSOR-8	NODE-11	ROUTER-10	NODE-11
309	4	0	Sensing	App3_SENSOR_APP	SENSOR-8	NODE-11	SENSOR-8	SENSOR-7
310	4	0	Sensing	App1_SENSOR_APP	SENSOR-1	NODE-11	SENSOR-1	SENSOR-2
311	4	0	Sensing	App3_SENSOR_APP	SENSOR-8	NODE-11	SENSOR-7	SENSOR-5
312	4	0	Sensing	App2_SENSOR_APP	SENSOR-3	NODE-11	SENSOR-3	SENSOR-4
313	4	0	Sensing	App1_SENSOR_APP	SENSOR-1	NODE-11	SENSOR-2	SENSOR-6
315	4	0	Sensing	App3_SENSOR_APP	SENSOR-8	NODE-11	SENSOR-5	SINKNODE-9

Figure 4-26: Packet Trace for Multipoint to Point

4.1.3.2 Point to Multipoint

Settings done in sample network

1. Set the all the properties same as Multipoint to Point scenario
2. Application properties has set as shown in below **Table 4-4.**

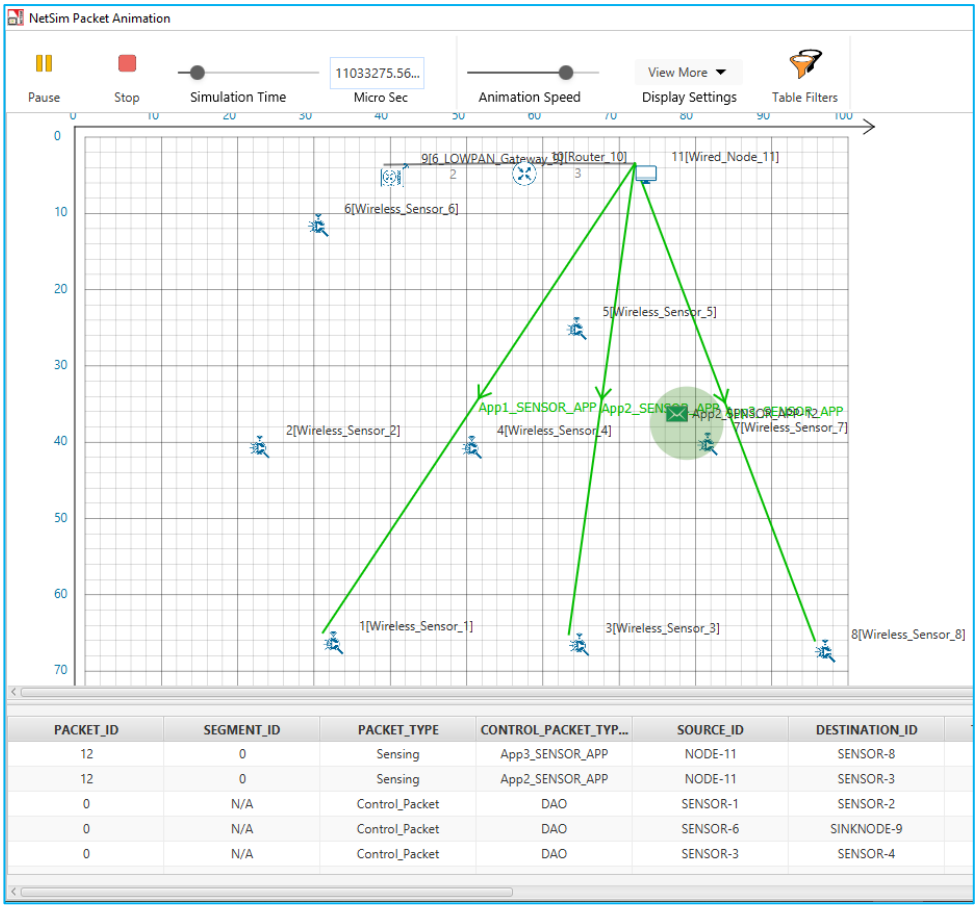
Application Properties			
Application ID	**Application Type**	**Source Id**	**Destination Id**
1	SENSOR_APP	11	1
2	SENSOR_APP	11	3
3	SENSOR_APP	11	8

Table 4-4: Application properties

3. In NetSim GUI Plots are Enabled. Run simulation 100s and observe that all the sensors are sending data to route node in animation window and also in packet trace.

Result

Animation window: Root sends data messages to the other nodes, producing a downward flow.



PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYP...	SOURCE_ID	DESTINATION_ID
12	0	Sensing	App3_SENSOR_APP	NODE-11	SENSOR-8
12	0	Sensing	App2_SENSOR_APP	NODE-11	SENSOR-3
0	N/A	Control_Packet	DAO	SENSOR-1	SENSOR-2
0	N/A	Control_Packet	DAO	SENSOR-6	SINKNODE-9
0	N/A	Control_Packet	DAO	SENSOR-3	SENSOR-4

Figure 4-27: Animation window for Point to Multipoint

Packet trace

	A	B	C	D	E	F	G	H
1	PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/APP_NAME	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID
531	12	0	Sensing	App1_SENSOR_APP	NODE-11	SENSOR-1	SENSOR-2	SENSOR-1
569	13	0	Sensing	App1_SENSOR_APP	NODE-11	SENSOR-1	SENSOR-2	SENSOR-1
578	13	0	Sensing	App3_SENSOR_APP	NODE-11	SENSOR-8	SENSOR-7	SENSOR-8
928	17	0	Sensing	App1_SENSOR_APP	NODE-11	SENSOR-1	SENSOR-2	SENSOR-1
1224	18	0	Sensing	App1_SENSOR_APP	NODE-11	SENSOR-1	SENSOR-2	SENSOR-1
1239	19	0	Sensing	App1_SENSOR_APP	NODE-11	SENSOR-1	SENSOR-2	SENSOR-1
1267	20	0	Sensing	App1_SENSOR_APP	NODE-11	SENSOR-1	SENSOR-2	SENSOR-1
1287	21	0	Sensing	App1_SENSOR_APP	NODE-11	SENSOR-1	SENSOR-2	SENSOR-1
1336	23	0	Sensing	App1_SENSOR_APP	NODE-11	SENSOR-1	SENSOR-2	SENSOR-1
1346	23	0	Sensing	App3_SENSOR_APP	NODE-11	SENSOR-8	SENSOR-7	SENSOR-8
1604	25	0	Sensing	App1_SENSOR_APP	NODE-11	SENSOR-1	SENSOR-2	SENSOR-1
1613	25	0	Sensing	App3_SENSOR_APP	NODE-11	SENSOR-8	SENSOR-7	SENSOR-8
1632	26	0	Sensing	App1_SENSOR_APP	NODE-11	SENSOR-1	SENSOR-2	SENSOR-1
1654	27	0	Sensing	App1_SENSOR_APP	NODE-11	SENSOR-1	SENSOR-2	SENSOR-1
1684	28	0	Sensing	App1_SENSOR_APP	NODE-11	SENSOR-1	SENSOR-2	SENSOR-1
1731	30	0	Sensing	App1_SENSOR_APP	NODE-11	SENSOR-1	SENSOR-2	SENSOR-1
1759	31	0	Sensing	App1_SENSOR_APP	NODE-11	SENSOR-1	SENSOR-2	SENSOR-1
2236	34	0	Sensing	App1_SENSOR_APP	NODE-11	SENSOR-1	SENSOR-2	SENSOR-1
2381	36	0	Sensing	App2_SENSOR_APP	NODE-11	SENSOR-3	SENSOR-4	SENSOR-3
2426	37	0	Sensing	App2_SENSOR_APP	NODE-11	SENSOR-3	SENSOR-4	SENSOR-3
2451	39	0	Sensing	App1_SENSOR_APP	NODE-11	SENSOR-1	SENSOR-2	SENSOR-1
2497	40	0	Sensing	App2_SENSOR_APP	NODE-11	SENSOR-3	SENSOR-4	SENSOR-3
2498	41	0	Sensing	App1_SENSOR_APP	NODE-11	SENSOR-1	SENSOR-2	SENSOR-1
2504	41	0	Sensing	App1_SENSOR_APP	NODE-11	SENSOR-1	SENSOR-2	SENSOR-1
2523	42	0	Sensing	App1_SENSOR_APP	NODE-11	SENSOR-1	SENSOR-2	SENSOR-1
2547	43	0	Sensing	App1_SENSOR_APP	NODE-11	SENSOR-1	SENSOR-2	SENSOR-1
2577	44	0	Sensing	App1_SENSOR_APP	NODE-11	SENSOR-1	SENSOR-2	SENSOR-1
2578	44	0	Sensing	App3_SENSOR_APP	NODE-11	SENSOR-8	SENSOR-7	SENSOR-8

Figure 4-28: Packet trace for Point to Multipoint

4.1.3.3 Point to Point

Settings done in sample network

1. Set the all the properties same as Multipoint to Point scenario.
2. Application properties has set as shown in below **Table 4-5.**

Application Properties			
Application ID	**Application Type**	**Source Id**	**Destination Id**
1	SENSOR_APP	1	5

Table 4-5: Application properties

3. In NetSim GUI Plots are Enabled. Run simulation 100s and observe that all the sensors are sending data to route node in animation window and also in packet trace.

Result

Animation window: Root sends data messages to the other nodes, producing a downward flow.

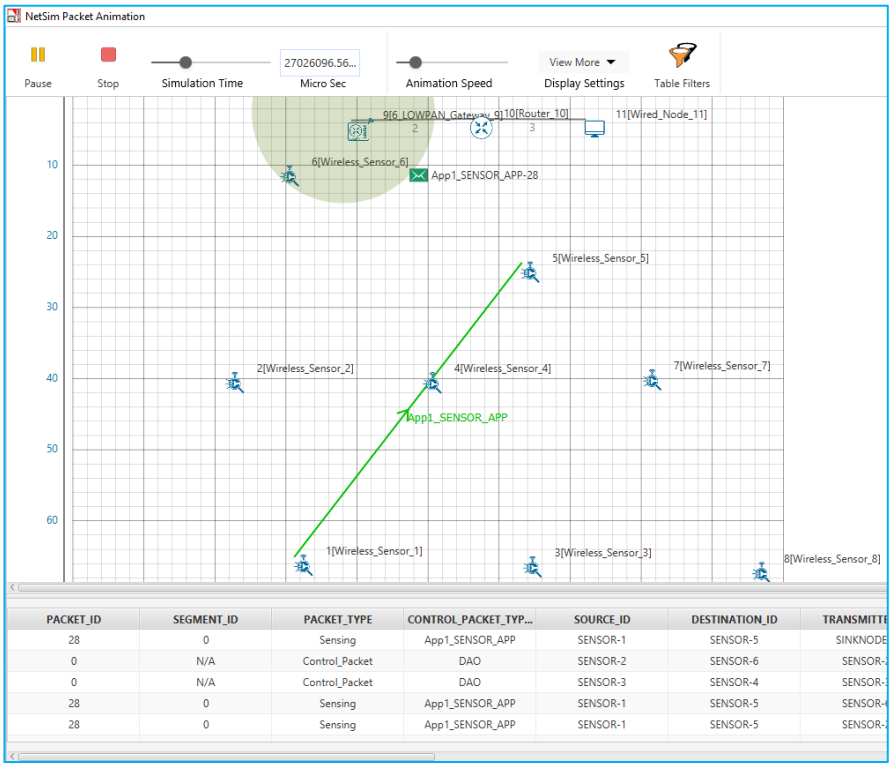


Figure 4-29: Animation window for Point to Point

Packet trace

	A	B	C	D	E	F	G	H
1	PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/APP_NAME	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID
228	2	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-1	SENSOR-2
229	2	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-2	SENSOR-6
230	2	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-6	SINKNODE-9
275	3	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-1	SENSOR-2
276	3	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-2	SENSOR-6
297	4	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-1	SENSOR-2
298	4	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-2	SENSOR-6
300	4	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-6	SINKNODE-9
335	5	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-1	SENSOR-2
338	5	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-2	SENSOR-6
340	5	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-6	SINKNODE-9
342	5	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SINKNODE-9	SENSOR-5
358	6	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-1	SENSOR-2
359	6	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-2	SENSOR-6
362	6	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-6	SINKNODE-9
364	6	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SINKNODE-9	SENSOR-5
376	7	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-1	SENSOR-2
377	7	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-2	SENSOR-6
378	7	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-6	SINKNODE-9
397	8	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-1	SENSOR-2
399	8	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-2	SENSOR-6
401	8	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-6	SINKNODE-9
408	8	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SINKNODE-9	SENSOR-5
427	9	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-1	SENSOR-2
428	9	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-2	SENSOR-6
432	9	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-6	SINKNODE-9
438	9	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SINKNODE-9	SENSOR-5
453	10	0	Sensing	App1_SENSOR_APP	SENSOR-1	SENSOR-5	SENSOR-1	SENSOR-2

Figure 4-30: Packet trace for Point to Point

4.1.3.4 Non-storing Mode

Settings done in sample network

1. Set the all the properties same as Multipoint to Point scenario.
2. Application properties has set as shown in below table:

Application Properties			
Application ID	**Application Type**	**Source Id**	**Destination Id**
1	SENSOR_APP	3	8

Table 4-6: Application properties

3. In NetSim GUI Plots are Enabled. Run simulation 100s and observe that all the sensors are sending data to route node in animation window and also in packet trace.

Result

Animation window: In non-storing MOP (MOP 1 (Point to Multipoint)), downward routes are supported, and the use of P2P and MP2P is allowed. However, all downward routes are maintained in the root node. Thus, the total downward traffic should be initially sent to the DODAG root and subsequently be forwarded to its destination.

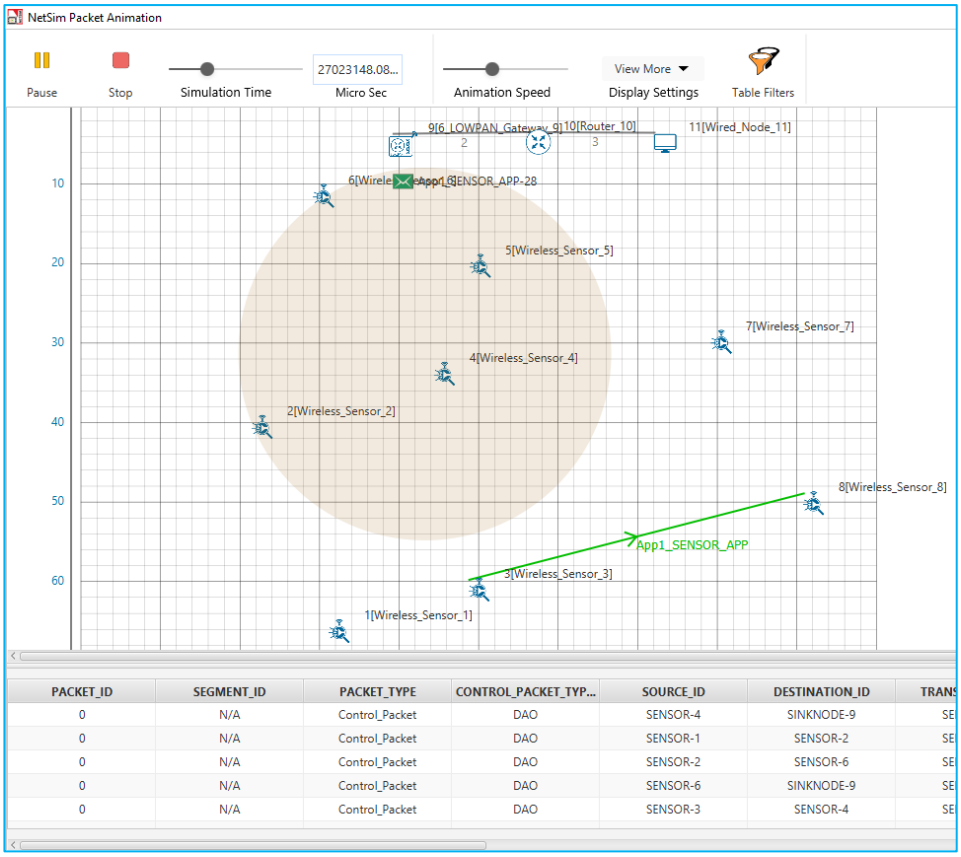


Figure 4-31: Animation window for RPL Non-Storing Mode

Packet trace

	A	B	C	D	E	F	G	H
1	PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/APP_NAME	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID
262	2	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-3	SENSOR-4
263	2	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-4	SINKNODE-9
301	3	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-3	SENSOR-4
302	3	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-4	SINKNODE-9
328	4	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-3	SENSOR-4
329	4	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-4	SINKNODE-9
374	5	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-3	SENSOR-4
375	5	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-4	SINKNODE-9
391	6	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-3	SENSOR-4
392	6	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-4	SINKNODE-9
408	7	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-3	SENSOR-4
409	7	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-4	SINKNODE-9
429	8	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-3	SENSOR-4
430	8	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-4	SINKNODE-9
431	8	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SINKNODE-9	SENSOR-5
435	8	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-5	SENSOR-7
438	8	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
466	9	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-3	SENSOR-4
467	9	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-4	SINKNODE-9
468	9	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SINKNODE-9	SENSOR-5
473	9	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-5	SENSOR-7
475	9	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
496	10	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-3	SENSOR-4
497	10	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-4	SINKNODE-9
500	10	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SINKNODE-9	SENSOR-5
503	10	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-5	SINKNODE-9
505	10	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SINKNODE-9	SENSOR-5
509	10	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-5	SINKNODE-9

Figure 4-32: Packet trace for RPL Non-Storing Mode

4.1.3.5 Storing Mode

Settings done in sample network

1. Set the all the properties same as Multipoint to Point scenario
2. Application properties has set as shown in below **Table 4-7.**

Application Properties			
Application ID	**Application Type**	**Source Id**	**Destination Id**
1	SENSOR_APP	3	8

Table 4-7: Application properties

3. In NetSim GUI Plots are Enabled. Run simulation 100s and observe that all the sensors are sending data to root node in animation window and also in packet trace.

Result

Animation window: In storing without multicast MOP (MOP 2 (Point to point)), downward routes are also supported, but are different from MOP 1 (Point to multipoint); the nodes maintain, individually, a routing table constructed using DAO messages to provide downward traffic. Hence, downward forwarding occurs without the use of the root node

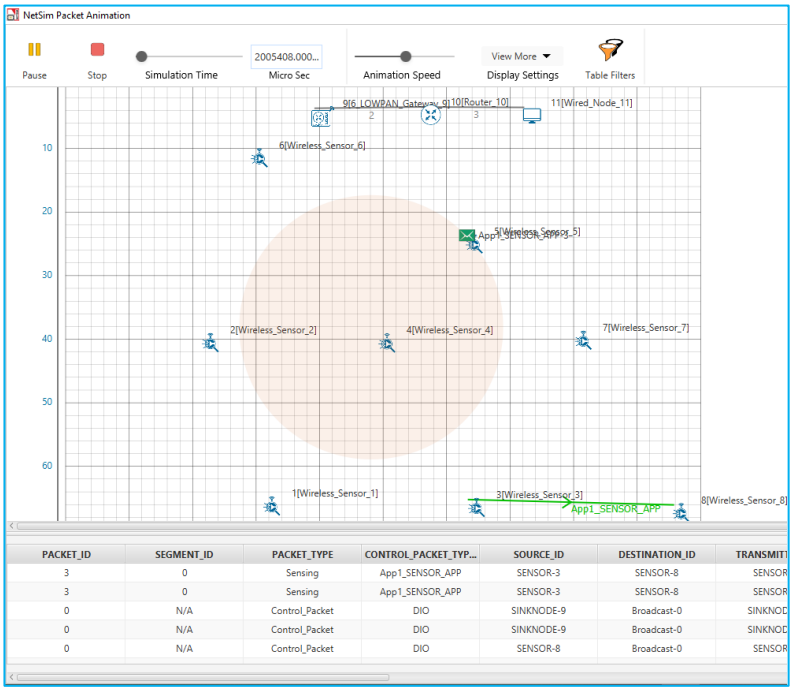


Figure 4-33: Animation window for RPL Storing Mode

Packet trace

	A	B	C	D	E	F	G	H
1	PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/APP_NAME	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID
277	3	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
301	4	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
367	6	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
377	7	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
405	8	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
436	9	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
482	11	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
499	12	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
514	13	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
533	14	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
1119	22	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
1137	23	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
2245	44	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
2275	46	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
2383	53	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
2400	54	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
2434	56	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
2455	57	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
2473	58	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
2490	59	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
2510	60	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
2531	61	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
2552	62	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
2569	63	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
2587	64	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
2605	65	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
2621	66	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8
2655	68	0	Sensing	App1_SENSOR_APP	SENSOR-3	SENSOR-8	SENSOR-7	SENSOR-8

Figure 4-34: Packet trace for RPL Storing Mode

4.2 WSN Example Simulation

4.2.1 Beacon Time Analysis

Open NetSim, Select **Examples->IOT-WSN->Wireless-Sensor-Networks->Beacon-Time-Analysis** as shown **Figure 4-35.**

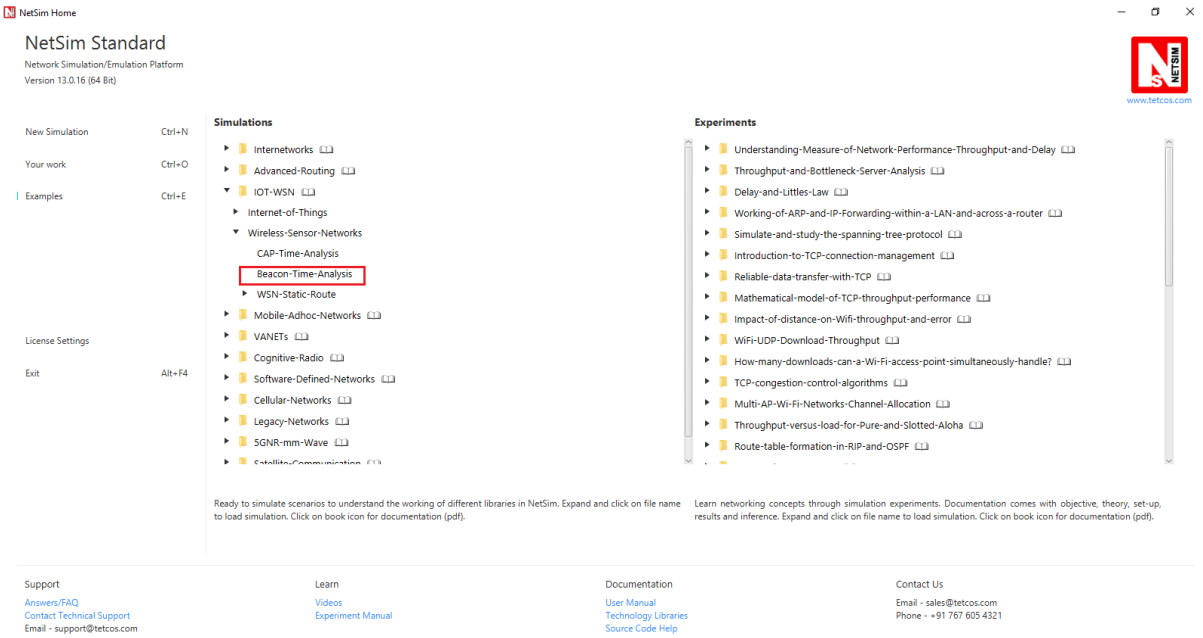


Figure 4-35: Featured Examples list

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

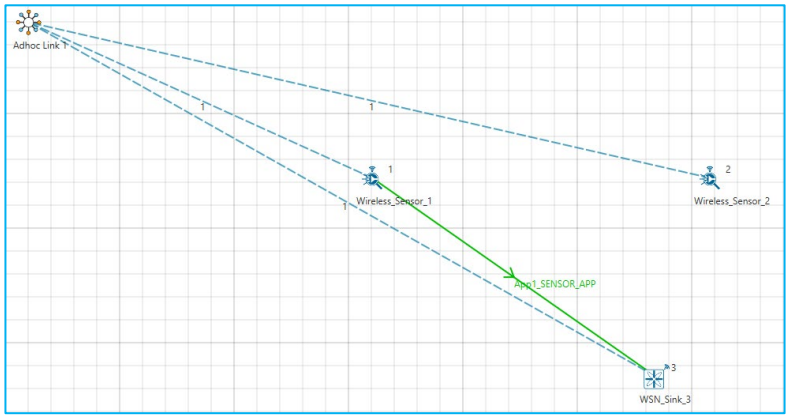


Figure 4-36: Network Topology

Settings done in sample config file

1. The following Environment properties are already set, as Manually Via Click and Drop.
2. In SinkNode-> Datalink Layer enable Beacon mode set Superframe Order (SO) -> 10 and Beacon Order (BO) -> 12.

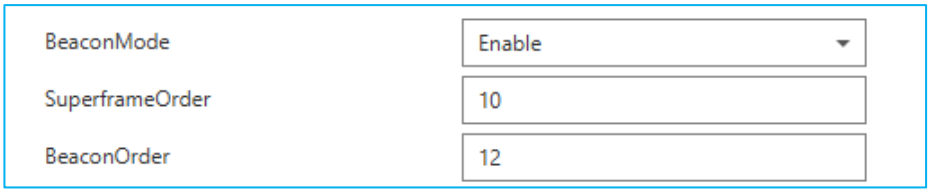


Figure 4-37: Datalink layer Properties window for Sinknode

3. In Adhoc Link Properties change Channel characteristics-> Path Loss only, Path Loss Model -> Log Distance and path loss exponent ->2.
4. Enable Packet Trace and Plots.
5. Set Simulation time as 200 sec.

Theoretical Beacon Time Calculation

- Beacon Interval (BI)= Super Frame duration (Active Period) + Inactive Period (IP).
- BI = abasesuperframe duration*2 ^BO = 15.36ms * 2^12 = 62914.56ms ~ 62s.
- SD = abasesuperframe duration*2 ^SO = 15.36ms * 2^10 = 15728.64ms.
- To find Inactive period, IP = BI – SD = 62914.56ms - 15728.64ms = 47185.92ms.
- Super Frame duration is divided into 16 slots (1st slot is allocated for beacon frame).
- Each slot time = 15728.64ms / 16 = 983.04ms

NetSim Results:

- Open packet trace and filter CONTROL_PACKET_TYPE to Zigbee_BEACON_FRAME, users should get four zigbee_beacon_frames at 0, 62.9, 125.8, 188.7 secs (approx.) for each Sensor_Node, because the time interval between two beacons frames is 62 seconds. Since we have 2 nodes so user can get 4 beacon frames for each node.
- 4 beacons were transmitted, so beacon time = 983.04ms * 4 = 3932.16millisec (since 1 beacon = 1 time slot). Check the beacon time in IEEE 802.15.4 metrics window.

4.2.2 CAP Time Analysis

Open NetSim, Select **Examples->IOT-WSN->Wireless-Sensor-Networks->CAP-Time-Analysis** as shown **Figure 4-38.**

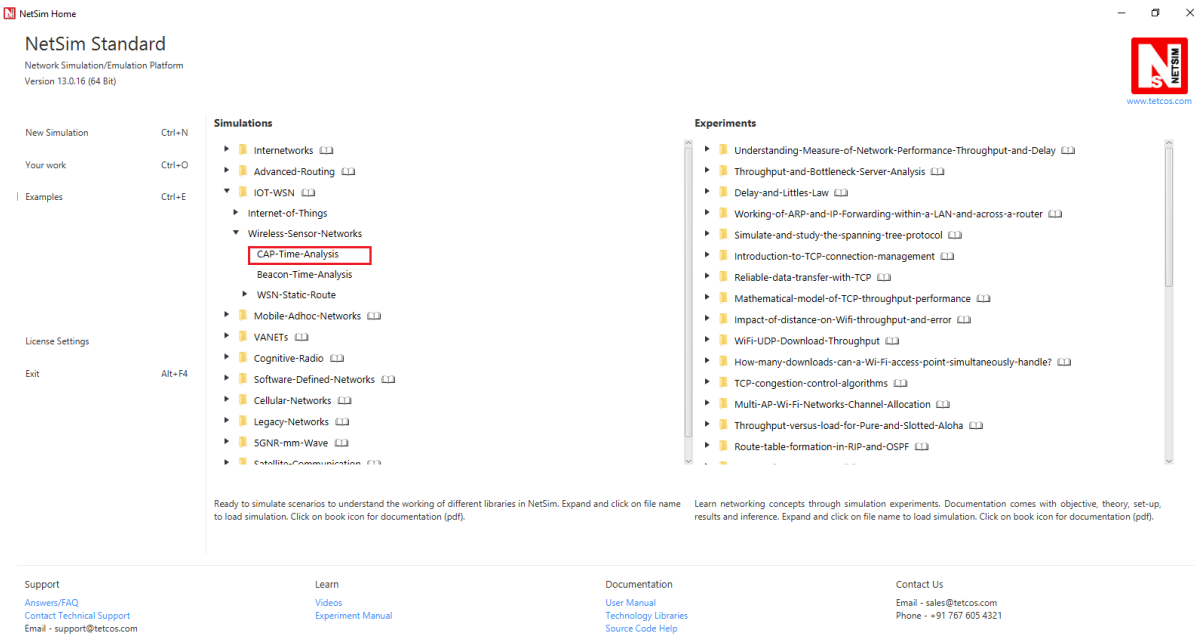


Figure 4-38: Featured Examples list

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

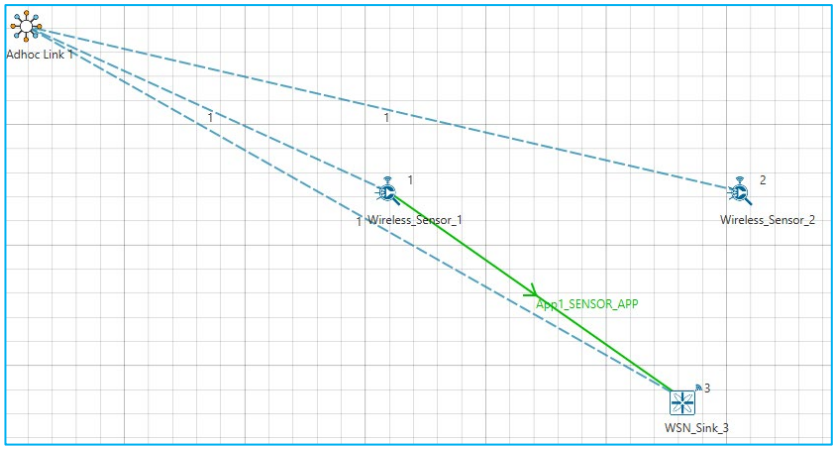


Figure 4-39: Network Topology

Settings done in example config file

1. The following Environment properties are already set, as Manually Via Click and Drop.
2. In SinkNode -> Datalink Layer enable Beacon mode set Superframe Order (SO) -> 10 and Beacon Order (BO) -> 12.

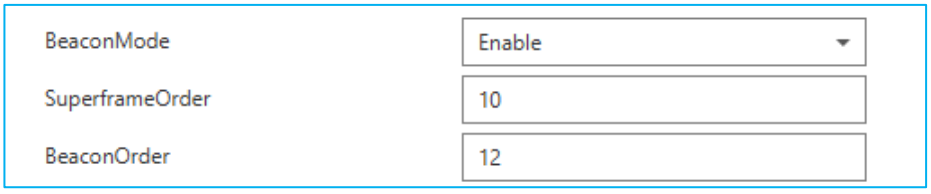


Figure 4-40: Datalink layer Properties window for Sinknode

3. In Adhoc Link Properties change Channel characteristics -> Path Loss only, Path Loss Model -> Log Distance and path loss exponent -> 2.
4. Enable Packet Trace and Plots.
5. Set Simulation time as 100 sec.

Theoretical CAP Time Calculation

- To find CAP time, BI is 62914.56ms -> So in 100s, two beacon frames should be transmitted at 0 & 62s.
- Check no. of beacon frames transmitted in 802.15.4 metrics.
- Here CFP = 0 because there is only 1 sensor.
- CAP Time = SD – beacon time = (15728.64ms) – (983.04ms) = 14745.6ms.
- Open packet trace and filter Control_Packet_Type to Zigbee_Beacon_Frame, users should get two zigbee_beacon_frames at 0, 62.9secs, because the time interval between two beacon frames is 62 seconds. Since we have 2 nodes so user can get 2 beacon fram for each node.
- Since two Beacon frames are transmitted, CAP time = 2 * 14745.6ms = 29491200µs.

NetSim Results:

- Check and compare the theoretical CAP time with NetSim simulation results in IEEE 802.15.4 metrics in Results Windows.
- CAP time = 29491200.0000Microsec.

4.2.3 Static Routing in WSN

Open NetSim, Select **Examples->IOT-WSN->Wireless-Sensor-Networks->WSN-Static-Route** as shown **Figure 4-41.**

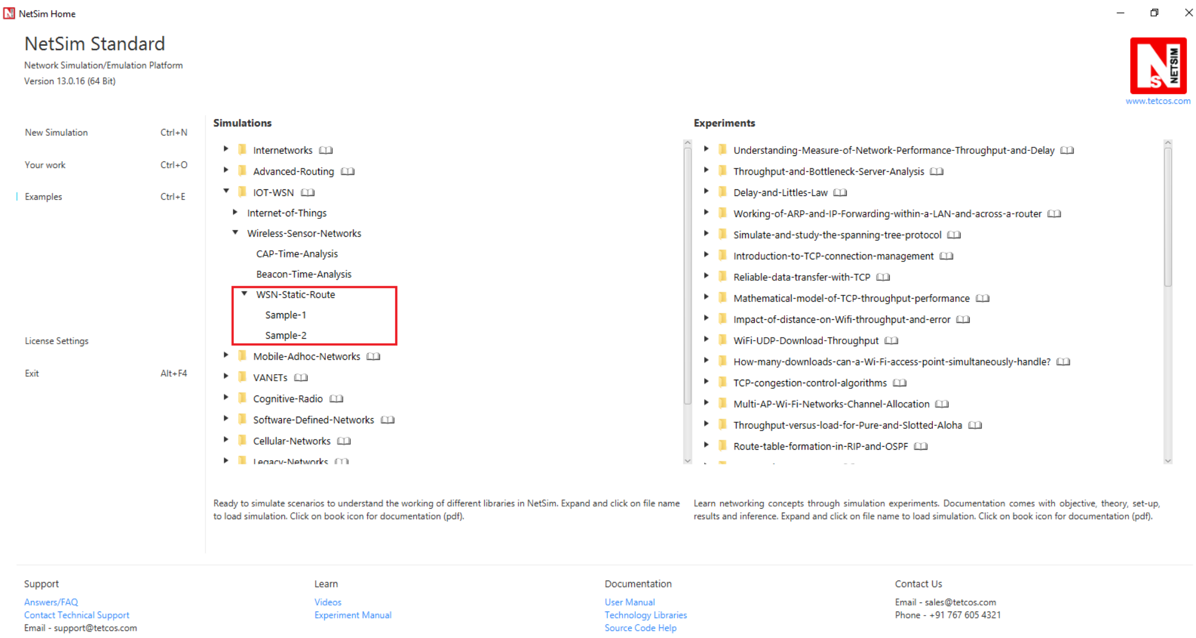


Figure 4-41: Featured Examples list

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

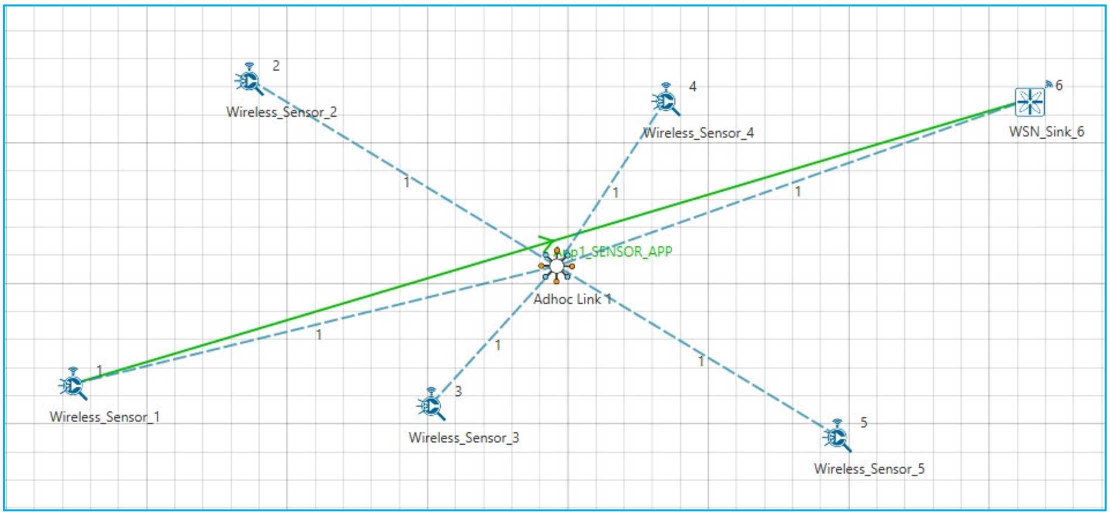


Figure 4-42: Network Topology

Sample-1:

Settings done in the network

- The following Environment properties are already set, as Manually Via Click and Drop.
- Set Application type as SENSOR_APP Source_Id as 1 and Destination_Id as 6
- Enable Packet trace and Plot option.
- Click on run simulation and set Simulation Time as 100 sec.

Results

Open packet animation and check Sensor 1 would send packets directly to the destination.

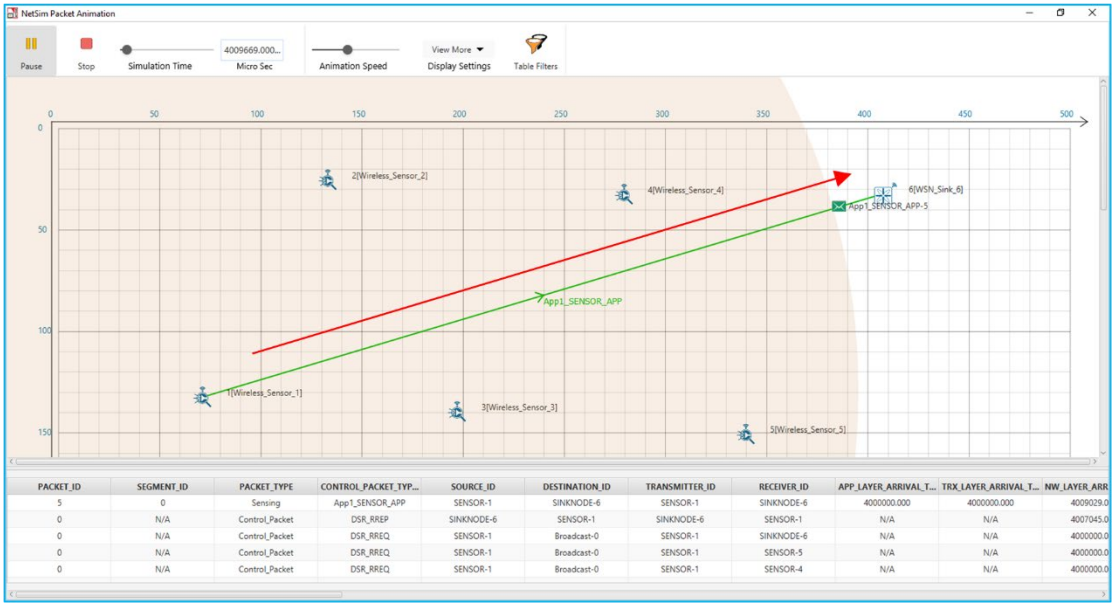


Figure 4-43: Packet animation window

Open packet trace and filter **PACKET_TYPE** column as **Sensing** and observe the packets flow.

PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/APP_NAME	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID
1	0	Sensing	App1_SENSOR_APP	SENSOR-1	SINKNODE-6	SENSOR-1	SINKNODE-6
1	0	Sensing	App1_SENSOR_APP	SENSOR-1	SINKNODE-6	SENSOR-1	SINKNODE-6
1	0	Sensing	App1_SENSOR_APP	SENSOR-1	SINKNODE-6	SENSOR-1	SINKNODE-6
2	0	Sensing	App1_SENSOR_APP	SENSOR-1	SINKNODE-6	SENSOR-1	SINKNODE-6
2	0	Sensing	App1_SENSOR_APP	SENSOR-1	SINKNODE-6	SENSOR-1	SINKNODE-6
2	0	Sensing	App1_SENSOR_APP	SENSOR-1	SINKNODE-6	SENSOR-1	SINKNODE-6
3	0	Sensing	App1_SENSOR_APP	SENSOR-1	SINKNODE-6	SENSOR-1	SINKNODE-6

Figure 4-44: Packet Trace

Sample-2:

Settings done in the network

- In Sample1, we have changed Wireless_Sensor properties as per the following:

Configuring Static Routes

Open Wireless_Sensor properties, go to network layer and click on **Configure Static Route IP** link, set **Network Destination**, **Gateway**, **Subnet Mask**, **Metrics**, and **Interface ID** as shown in below screenshot and click on **ADD**.

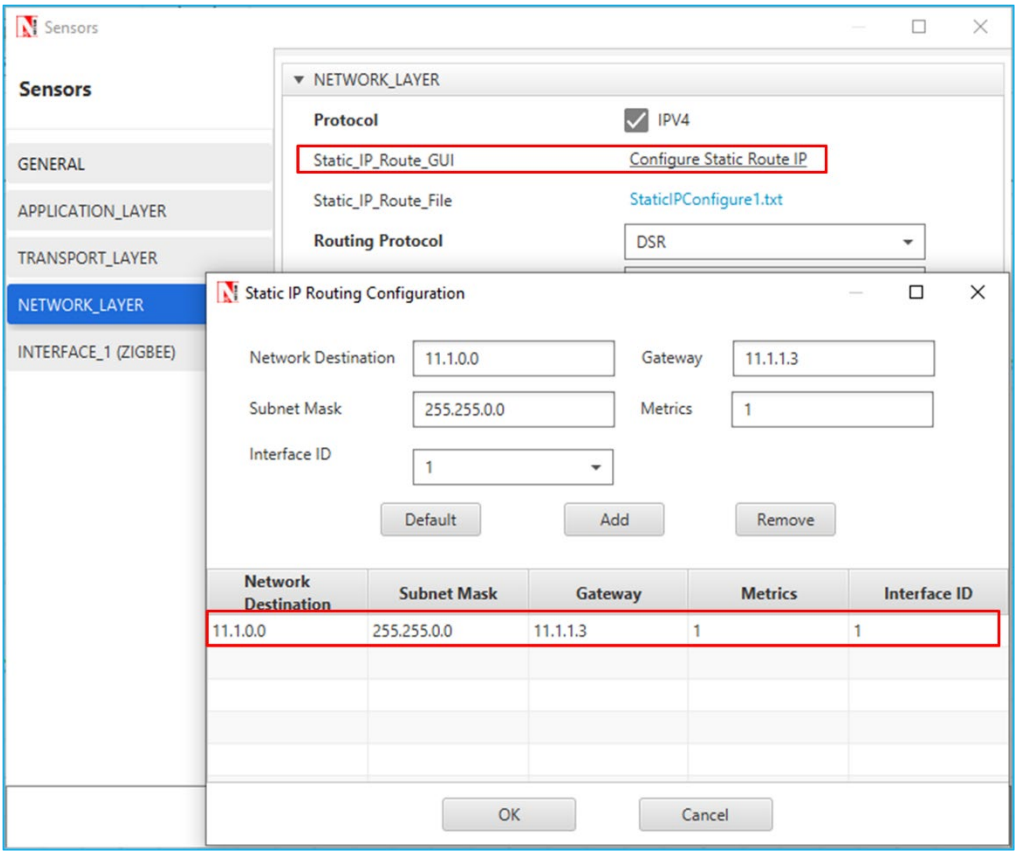


Figure 4-45: Static IP Routing Configuring window

Device	Network Destination	Gateway	Subnet Mask	Metrics	Interface ID
Wireless_Sensor_1	11.1.0.0	11.1.1.3	255.255.0.0	1	1
Wireless_Sensor_2	11.1.0.0	11.1.1.4	255.255.0.0	1	1
Wireless_Sensor_3	11.1.0.0	11.1.1.5	255.255.0.0	1	1
Wireless_Sensor_4	11.1.0.0	11.1.1.6	255.255.0.0	1	1

Table 4-8: Static Route Configuration for Sensors

- After setting the properties click on run simulation and set Simulation Time as 100 sec.

Results

Open packet animation and check packets would reach the destination via the configured static route,

SENSOR_1 → SENSOR_2 → SENSOR_3 → SENSOR_4 → SENSOR_5 → SINKNODE_6

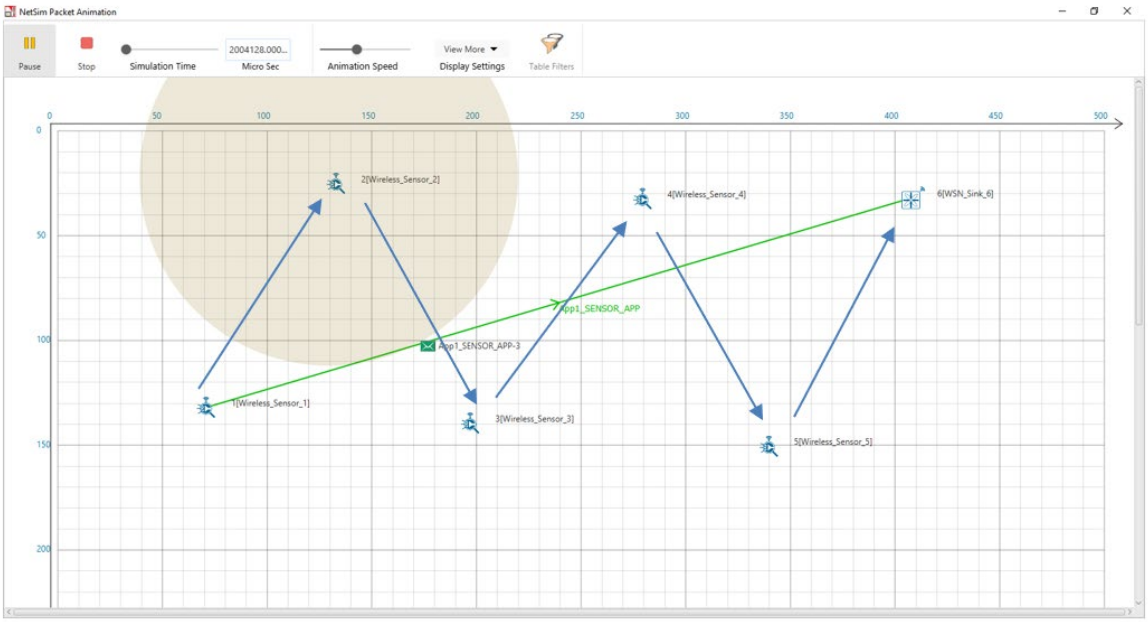


Figure 4-46: Packets flow in animation window as specified in the static route configuration

Open packet trace and filter **PACKET_TYPE** column to **Sensing** and observe the packets flow as specified in the static route configuration.

SENSOR_1 → SENSOR_2 → SENSOR_3 → SENSOR_4 → SENSOR_5 → SINKNODE_6

PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/APP_NAME	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID
1	0	Sensing	App1_SENSOR_APP	SENSOR-1	SINKNODE-6	SENSOR-1	SENSOR-2
1	0	Sensing	App1_SENSOR_APP	SENSOR-1	SINKNODE-6	SENSOR-2	SENSOR-3
1	0	Sensing	App1_SENSOR_APP	SENSOR-1	SINKNODE-6	SENSOR-3	SENSOR-4
1	0	Sensing	App1_SENSOR_APP	SENSOR-1	SINKNODE-6	SENSOR-4	SENSOR-5
1	0	Sensing	App1_SENSOR_APP	SENSOR-1	SINKNODE-6	SENSOR-5	SINKNODE-6
1	0	Sensing	App1_SENSOR_APP	SENSOR-1	SINKNODE-6	SENSOR-5	SINKNODE-6

Figure 4-47: Packet flow in Packet Trace

5 Reference Documents

[1] O. Landsiedel, K. Wehrle and S. Gotz, "Accurate Prediction of Power Consumption in Sensor Networks. University of Tubingen, Germany," 2005.

[2] T. Winter, P. Thubert, A. Brandt, J. Hui, R. Kelsey, P. Levis, K. Pister, R. Struik, J. Vasseur and R. Alexander, "IETF RFC 6550: RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks".

[3] "IEEE Standard 802.15.4-2011: Low-Rate Wireless Personal Area Networks (LR-WPANs)".

6 Latest FAQs

Up to date FAQs on NetSim's IoT/ WSN library is available at https://tetcos.freshdesk.com/support/solutions/folders/14000105117