

**NetSim<sup>®</sup>**

Accelerate Network R & D

# **TDMA Radio Networks**

A Network Simulation & Emulation Software

By



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# 1 Introduction

**NOTE:** This component (technology library) is available only in NetSim Pro version.

NetSim TDMA radio network module features packet level simulation of voice, video and data communication over VHF/UHF/L-band/S-band/C-band/Ku/Ka/K radios running MANET waveforms. These use-cases can range from simple hand-held radios to vehicular radios, to aeronautical radios.

A Mobile Adhoc Network (MANET) is an autonomous system of mobile nodes. Such networks have dynamic (sometimes rapidly changing), random, multi-hop topologies which are composed of relatively bandwidth-constrained wireless links. MANETs must therefore support efficient operation in mobile wireless environments by incorporating routing functionality into mobile nodes.

NetSim TDMA Radio Networks module features:

- IP based MANET routing protocols DSR, AODV, OLSR and ZRP. Please refer to the MANET technology library document for detailed information.
- Datalink Layer:
  - (a) TDMA: Time division multiple access (TDMA) allows several users to share the same channel by dividing time into slots. In NetSim's TDMA implementation (based on TDMA) the mapping of nodes to time slots is round robin.
  - (b) Dynamic TDMA: In D-TDMA, the mapping of nodes to time slots is user configurable, instead of being round robin. The options are (i) Round Robin, (ii) Demand based, and (iii) File based (slot planner).
- PHY Layer:
  - (a) Frequency Range: VHF, UHF, L-Band, S-Band, C-Band, Ka, K, Ku.
  - (b) Single channel. Narrowband or Wideband.
  - (c) Modulation Schemes: GMSK, BPSK, QPSK, 16QAM and 64QAM, CPM and MSK.
  - (d) A wide range of propagation models covering pathloss, fading and shadowing.

The NetSim TDMA radio networks (DTDMA protocol) library interfaces with

- NetSim Component 1, Internetworks library
- NetSim Component 4, MANET library

Connectivity to external networks is provided through bridge nodes.

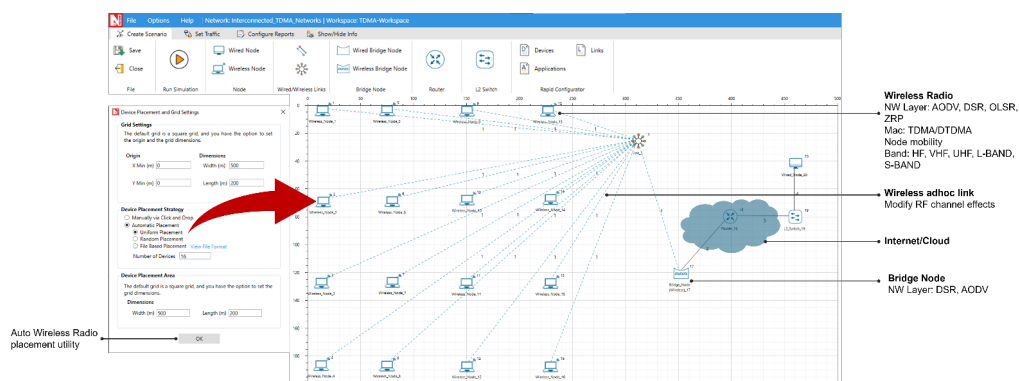


**Figure 1-1:** A typical TDMA Network scenario connected via a bridge node, and connected to an external network through a router in NetSim

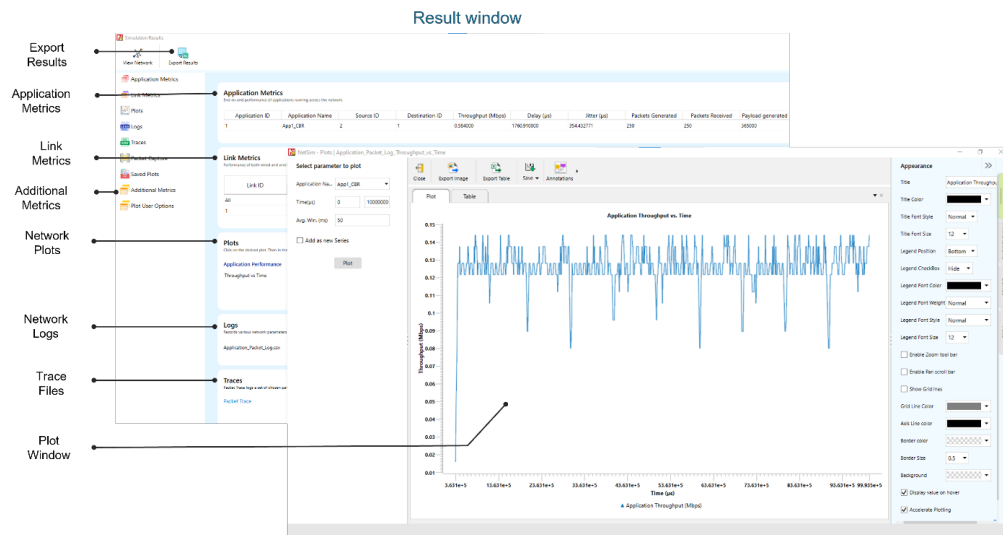


**Figure 1-2:** The Result dashboard and Plot window shown in NetSim after completion of simulation.

## 2 Simulation GUI

Open NetSim, go to New Simulation → TDMA Radio Networks.

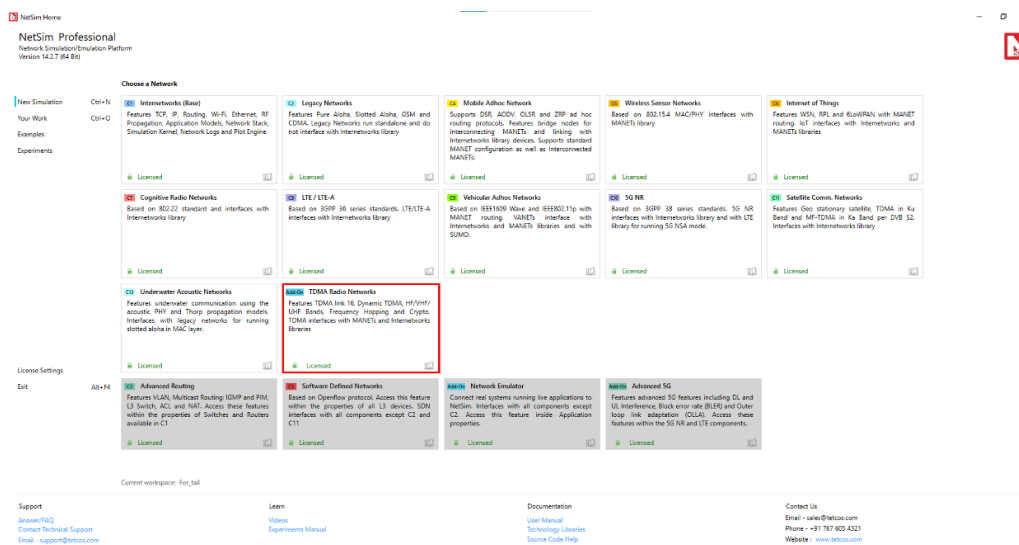


**Figure 2-1:** NetSim Home Screen

## 2.1 NetSim TDMA Network Setup

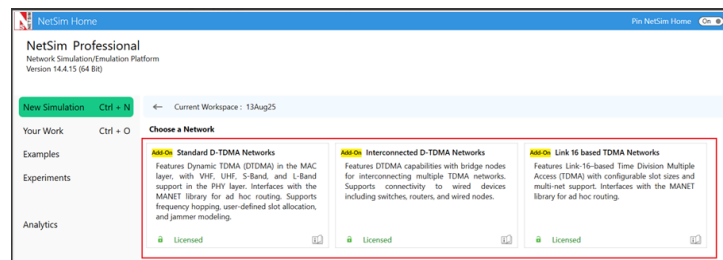


Figure 2-2: TDMA Network Setup window.

### 2.1.1 Deployment Architecture

The deployment options are grouped into three categories. The Standard D-TDMA option includes only wireless nodes without any bridge nodes. The Interconnected D-TDMA option enables users to connect two or more D-TDMA networks using a bridge node. The Link 16-based TDMA option features wireless nodes operating with the TDMA protocol.

**Standard D-TDMA:** In Standard D-TDMA, a network scenario can be created using Ad-hoc links and wireless nodes. Standard D-TDMA features Dynamic TDMA in MAC layer, VHF, UHF, S-band, C-band, L-band, Ku, K and Ka band in the PHY layer. Additionally, it supports frequency hopping, user-defined slot allocation, jammer modeling, and other advanced capabilities.

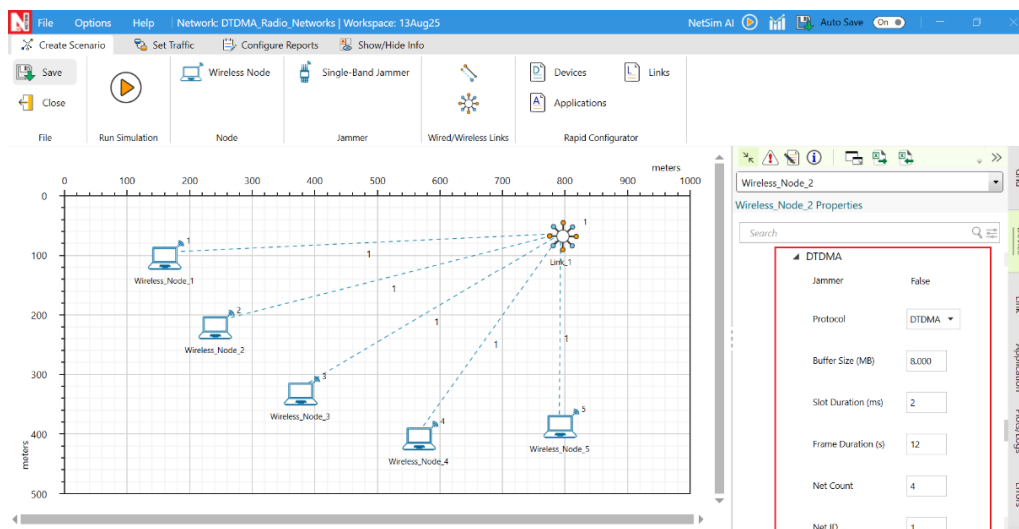


Figure 2-3: A Single D-TDMA scenario

**Interconnected D-TDMA:** In interconnected D-TDMA, a network scenario can be created using multiple D-TDMA, bridge nodes for interconnecting multiple D-TDMA networks, and wired devices like switches, routers, and nodes. Interconnected D-TDMA features Dynamic TDMA in MAC layer, VHF, UHF, S-band, C-band, L-band, Ku, K and Ka in the PHY layer.

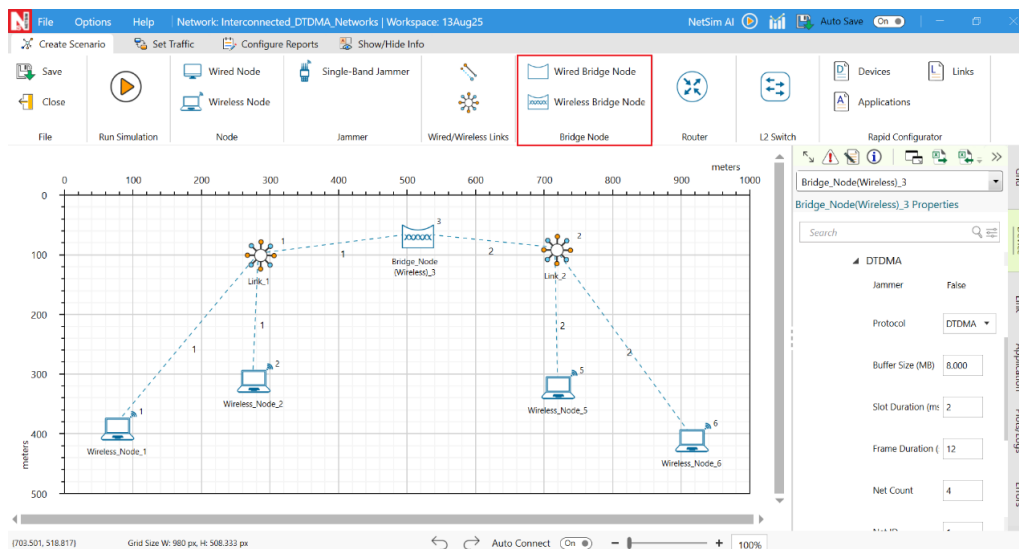


**Figure 2-4:** *Interconnected (Multiple) D-TDMA Scenario.*

**Link 16 based TDMA Networks:** In Link 16 based TDMA Networks, a network scenario can be created using Ad-hoc links and wireless nodes. It features TDMA in MAC layer, VHF, UHF, S-band, C-band, L-band, Ku, K and Ka band in the PHY with configurable slot size and multi net support.

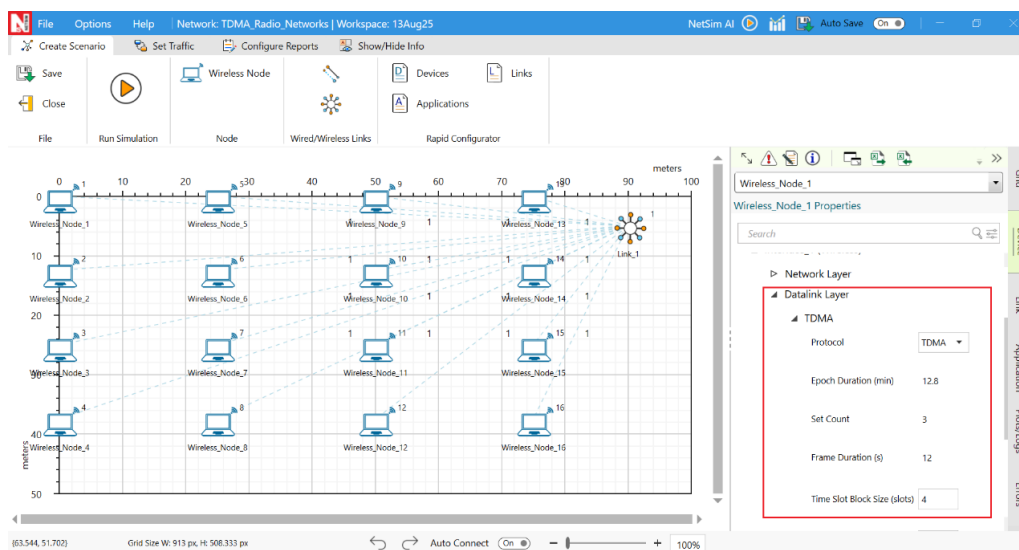


**Figure 2-5:** *Single TDMA network.*

## 2.2 Fast Configuration Window

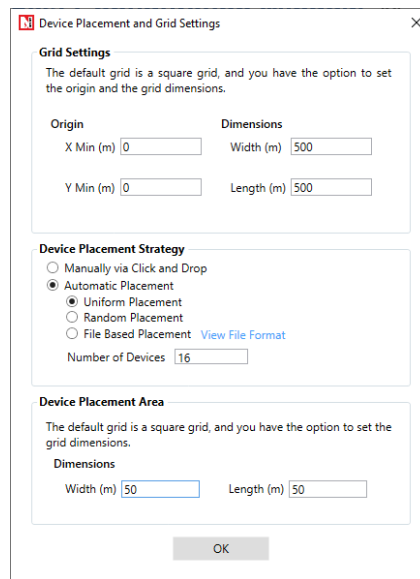


**Figure 2-6:** *Fast Configuration window*

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

- (i) Grid Origin: The ‘Grid Origin’ refers to the intersection point of the system’s axes. NetSim supports any (X, Y) setting for the origin and not just (0, 0).
- (ii) Grid Dimension: The width parameter represents the maximum along X from the origin and the height parameter represents the maximum along Y from the origin.
- (iii) Device placement area: The “Device Placement Area” allows users to specify the width and length of the area where devices are used when using the auto placement utility. This area must be less than or equal to the “Grid Area”.

## 2.3 Create Scenario

Click on the Wireless Node in the Toolbar. Next, click on the environment where you want to drop it inside the grid.

(NOTE: A Node cannot be placed on another Node. A Node cannot float outside of the grid.)

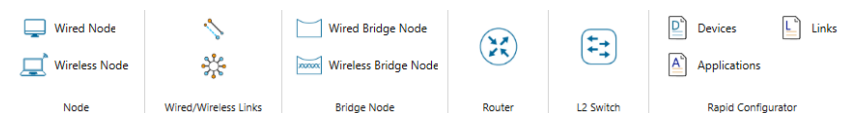


**Figure 2-7:** *Devices present on top ribbon*

## 2.4 Set Node Properties

- Right click on the appropriate node to select Properties.

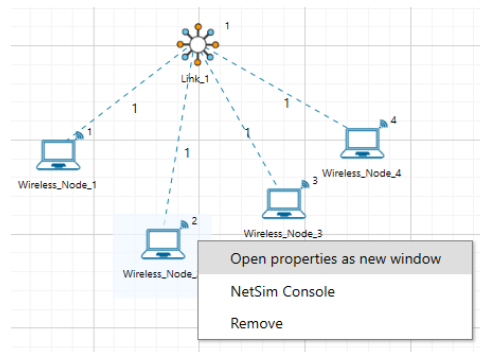


**Figure 2-8:** *Network Topology*

- In Interface 1 Wireless, go to DATALINK LAYER. Protocol is set to TDMA/DTDMA. In Wireless Node, Routing Protocol in Network Layer and all user editable properties in Datalink Layer are Global, Physical Layer are local, i.e., changing properties in one node will not automatically reflect in the others in that network.

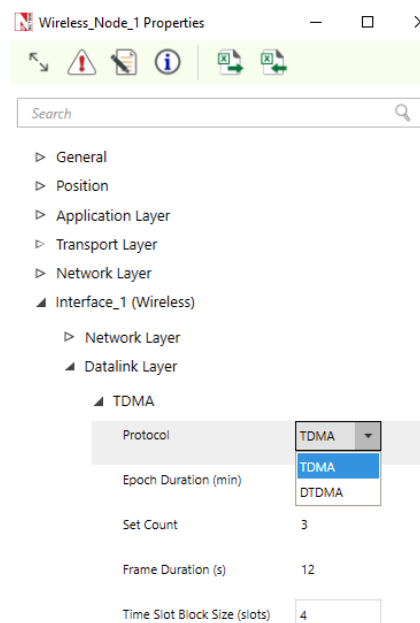


**Figure 2-9:** *Datalink layer properties window for wireless node*

- In Network Layer properties, Link layer Ack Type should be selected as “Network Layer Ack” for DSR Routing Protocol.
- Furthermore, in Physical layer, we can select the frequency bands (VHF/UHF/L-Band/S-Band/C-Band/Ka/K/Ku). Users can modify the lower frequency range and the Bandwidth. The sum of the Lower frequency and Bandwidth gives the Upper frequency. Users can also select the modulation techniques such as BPSK/QPSK/16-QAM/64-QAM/GMSK/CPM/MSK, coding rate 1/2, 2/3, 3/4, 5/6 and, an option to turn ON/OFF frequency hopping is also provided.
- Bandwidth is used in central frequency and noise calculations. The pathloss calculations are explained in Propagation-Models.pdf manuals.
- Lower and Upper frequency are used for frequency hopping and central frequency calculations.
- Time Slot Block Size is the number of slots that can be assigned to a block. As we increase time slot block size from 4 to 10, the max packet size can vary between 48B to 150B.

## 2.5 Set Environment Properties

- Right click on Adhoc link and open properties as new window.
- Select the Channel Characteristics and set the parameters accordingly.

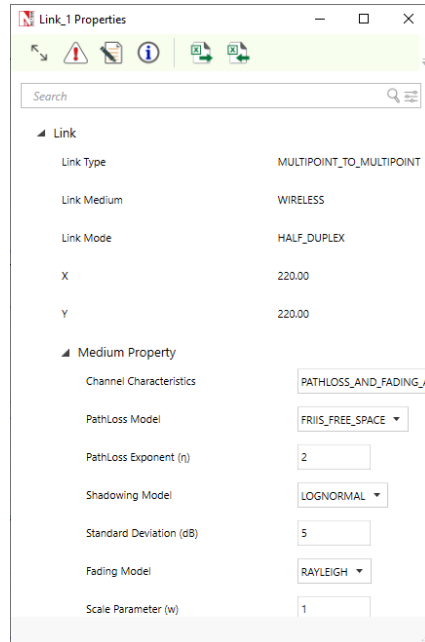


**Figure 2-10:** *Wireless Link Properties*

## 2.6 Set Application Properties

- Click on the Set Traffic option present on the ribbon and set properties. Multiple applications can be generated by clicking Applications option present in the Rapid configurator window.

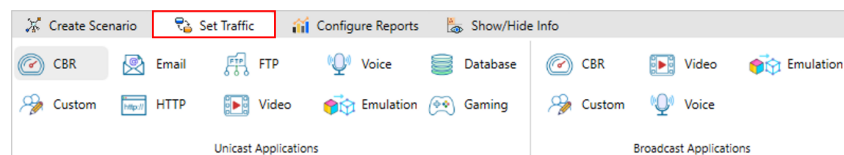


**Figure 2-11:** *Application icon present on top ribbon*

- Set the values according to requirement as shown in the figure below.

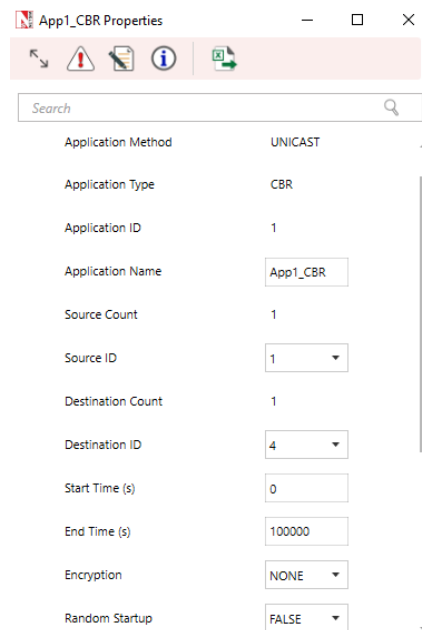


**Figure 2-12:** Application Window

## 2.7 Enable Packet Trace, Event Trace & Plots (Optional)

Click Packet Trace / Event Trace icon in the Configure Report option and check Enable Packet Trace / Event Trace check box. To get detailed help, please refer sections 8.2, 8.4 and 8.5 in User Manual.

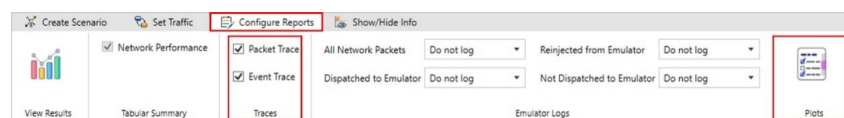


**Figure 2-13:** Enable Packet Trace, Event Trace options.

## 2.8 Enable protocol specific logs and plots

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

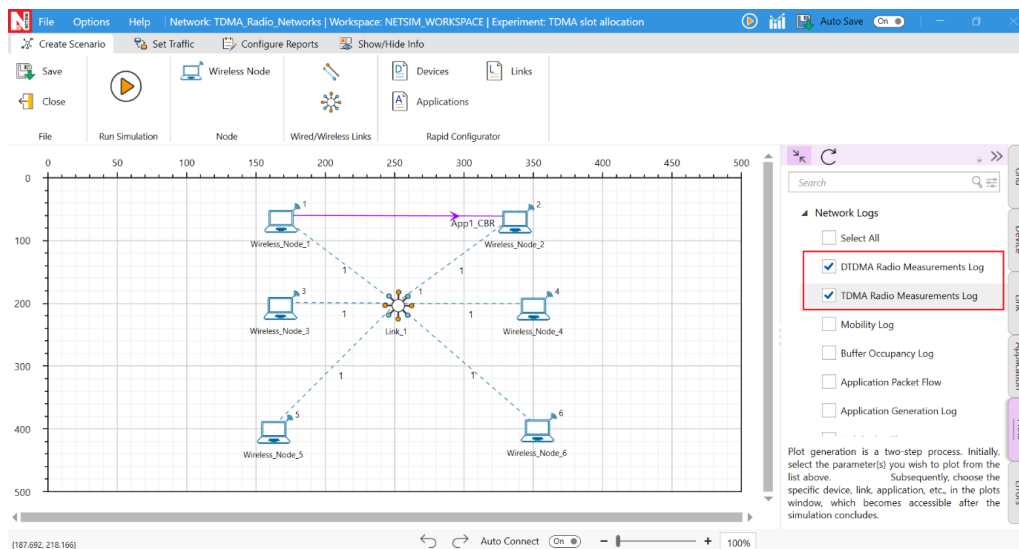


**Figure 2-14:** Enabling the TDMA and DTDMA Radio measurements log

Similarly, users can enable the Fading loss vs time, SNR vs time and other plots for TDMA and DTDMA radio measurements.

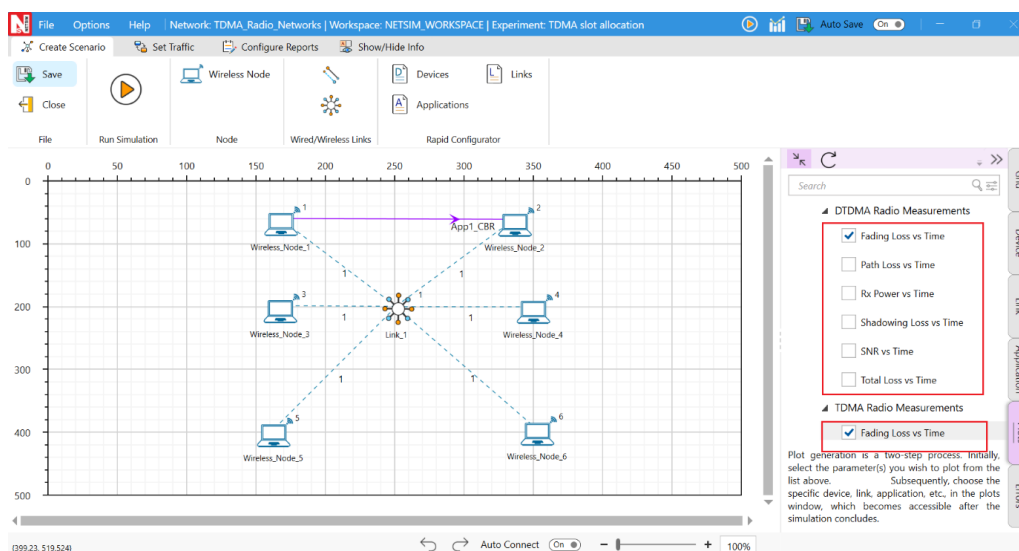


**Figure 2-15:** Enabling the TDMA and DTDMA Radio measurements plots

## 2.9 Run Simulation

Click on Run Simulation icon on the top toolbar.

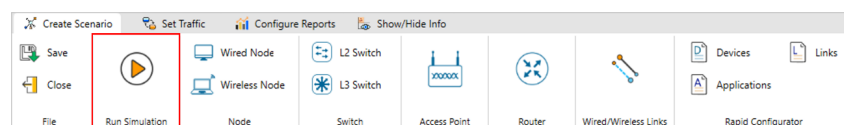


**Figure 2-16:** Run Simulation option on top ribbon

## 3 Model Features

### 3.1 L3 Routing

Refer to the MANETs technology library (PDF) document for detailed information. Note that standard TDMA/DTDMA networks support DSR, OLSR, ZRP and AODV protocols and interconnected TDMA/DTDMA networks support AODV and DSR. Static routes can also be configured as explained in Internetworks technology library document, Section Configuring Static Routing in NetSim. Users can also refer to the MANETs technology library document, to understand the working of wired and wireless bridge nodes.

### 3.2 TDMA

#### 3.2.1 TDMA MAC

**Table 3-1:** *TDMA MAC Config Parameters.*

| Parameter                    | Type * | Range          | Description                                                                                                                                                                                                                              |
|------------------------------|--------|----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Epoch Duration (min)         | Fixed  | 12.8           | An Epoch is 12.8 minutes long and consists of 64 frames                                                                                                                                                                                  |
| Set Count                    | Fixed  | 3              | The time slots of an epoch are grouped into 3 sets. Each contains 32,768 slots numbered from 0 to 32,767.                                                                                                                                |
| Frame Duration (s)           | Fixed  | 12             | The time between the beginning of a frame and the end of that frame. The duration of 1 frame in TDMA is 12s.                                                                                                                             |
| Time Slot Block Size (slots) | Global | 1-10           | The time slots are allocated to each terminal as a block of slot, the size of this block of slot is Time slot block size and the default Time Slot Block Size value is 4 in NetSim. The Time Slot Block Size should always be $\geq 2$ . |
| Net Count                    | Global | 1-126          | Multiple nets can be constructed by stacking several nets. The 7bit net number allows a network of up to 128 nets and the default Net Count value is 26 in NetSim.                                                                       |
| Net Id                       | Local  | 1-126          | The Net Id determines the network address. The nets are numbered from 1-26. The default value in NetSim is 1.                                                                                                                            |
| Slot Duration (ms)           | Fixed  | 7.8125         | The time between the beginning of a slot and the end of that slot. The duration of 1 slot in TDMA is 7.8125ms.                                                                                                                           |
| MAC Address                  | Fixed  | Auto generated | The MAC address is a unique value associated with a network adapter. This is also known as hardware address or physical address. This is a 12-digit hexadecimal number (48 bits in length).                                              |

### 3.2.2 TDMA PHY

**Table 3-2:** *TDMA MAC PHY Config Parameters.*

| Parameter                | Type * | Range      | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|--------------------------|--------|------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Transmit Power (W)       | Local  | 1 - 100    | It is the signal intensity of the transmitter. The default Transmit Power is 20 W in NetSim.                                                                                                                                                                                                                                                                                                                                                                                                         |
| Antenna Gain (dBi)       | Local  | 0 - 1000   | Antenna Gain describes the ratio of how much power is transmitted/received in a particular direction or pattern of peak radiation to that of an isotropic antenna. The default value is 0 dBi.                                                                                                                                                                                                                                                                                                       |
| Antenna Height (m)       | Local  | 0 - 100    | Antenna height is only considered when using the following propagation models: Cost 231 Hata Urban, Cost 231 Hata Suburban, Hata Urban, Hata Suburban. These are propagation models used to model urban scenarios where the antenna height is an important parameter to compute the pathloss. When using these models, the antenna height represents the height of the antenna above the ground. Since these are urban scenarios, it is assumed that the nodes are always on the ground (i.e., z=0). |
| Frequency (MHz)          | Local  | 30 - 3000  | The frequency at which the device is operating. The default Frequency is 960 MHz.                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Bandwidth (MHz)          | Local  | 0.1 – 20.0 | Bandwidth is a range of frequencies occupied by the radio communication signal. The default bandwidth value in NetSim is 3 MHz.                                                                                                                                                                                                                                                                                                                                                                      |
| Receiver Sensitivity dBm | Local  | 0 to -120  | Receiver Sensitivity is the lowest power at which the receiver can detect an RF signal and demodulate data. The default Receiver Sensitivity value is -85 dBm.                                                                                                                                                                                                                                                                                                                                       |

### 3.2.3 PHY Data Rate

The PHY rate for TDMA networks is set to 25 Kbps. Users can only modify this by changing the following line of code in TDMA.h file

```
#define DATA_RATE 0.025 //mbps
```

### 3.2.4 TDMA Packet size

TDMA protocol in NetSim supports a fixed data rate of 25 Kbps. Since TDMA currently does not support packet fragmentation/reassembly, the packet size in the application layer should be correctly set considering the overheads in different layers. If the overall packet size exceeds the maximum packet size, then packets will be discarded, leading to zero throughput.

Equation for calculating the Maximum packet size for TDMA protocol is mentioned below

$$\text{Maximum Packet size (Bytes)} = \frac{\text{Time Slot block size (slots)} \times \text{slot duration (ms)} \times \text{Data Rate (Kbps)}}{8} \quad (1)$$

By default, Time slot block size is 4 and user can vary it between 1 to 10 in GUI, Slot duration is fixed to 7.8125 ms and data rate to 25 Kbps. Hence the maximum packet size that TDMA can handle, including overheads, is 97 Bytes.

**Table 3-3:** *Overheads of protocols in different layers*

| Protocols                  | Overheads (Bytes) |
|----------------------------|-------------------|
| TCP                        | 20                |
| UDP                        | 8                 |
| IP                         | 20                |
| AODV/ZRP/OLSR              | 0                 |
| DSR with Link layer ACK    | 8                 |
| DSR with Network layer ACK | 12                |
| MAC layer                  | 5                 |
| Physical layer             | 5                 |

**NOTE:** For each additional hops 4 bytes are added.

Calculating the Maximum application layer payload for different protocols.

I. AODV/ ZRP/OLSR with TCP

$$\begin{aligned} \text{Maximum application layer payload (Bytes)} &= 97 - (\text{TCP overheads} + \text{IP overheads} + \text{TDMA overheads}) \\ &= 97 - (20 + 20 + 10) = 47 \text{ Bytes.} \end{aligned}$$

II. AODV/ ZRP/OLSR with UDP

$$\begin{aligned} \text{Maximum application layer payload (Bytes)} &= 97 - (\text{UDP overheads} + \text{IP overheads} + \text{TDMA overheads}) \\ &= 97 - (8 + 20 + 10) = 59 \text{ Bytes.} \end{aligned}$$

III. DSR with link layer ACK and TCP

$$\begin{aligned} \text{Maximum application layer payload (Bytes)} &= 97 - (\text{TCP overheads} + \text{IP overheads} + \text{DSR overheads} \\ &\quad + \text{TDMA overheads}) \\ &= 97 - (20 + 20 + 8 + 10) = 39 \text{ Bytes.} \end{aligned}$$

IV. DSR with link layer ACK and UDP

$$\begin{aligned} \text{Maximum application layer payload (Bytes)} &= 97 - (\text{UDP overheads} + \text{IP overheads} + \text{DSR overheads} \\ &\quad + \text{TDMA overheads}) \\ &= 97 - (8 + 20 + 8 + 10) = 51 \text{ Bytes} \end{aligned}$$

V. DSR with network layer ACK and TCP

$$\begin{aligned} \text{Maximum application layer payload (Bytes)} &= 97 - (\text{TCP overheads} + \text{IP overheads} + \text{DSR overheads} \\ &\quad + \text{TDMA overheads}) \\ &= 97 - (20 + 20 + (8 + 4) + 10) = 35 \text{ Bytes.} \end{aligned}$$

VI. DSR with network layer ACK and UDP

$$\begin{aligned} \text{Maximum application layer payload (Bytes)} &= 97 - (\text{UDP overheads} + \text{IP overheads} + \text{DSR overheads} \\ &\quad + \text{TDMA overheads}) \\ &= 97 - (8 + 20 + (8 + 4) + 10) = 47 \text{ Bytes} \end{aligned}$$

### 3.2.5 TDMA Radio Measurements Log

NetSim TDMA Radio measurements csv log file records pathloss, shadowing loss, fading loss, received power, transmitted power, SNR. This log can be enabled by clicking on configure reports in top ribbon > Plots > TDMA Radio Measurements log option under the Network Logs section as shown below:

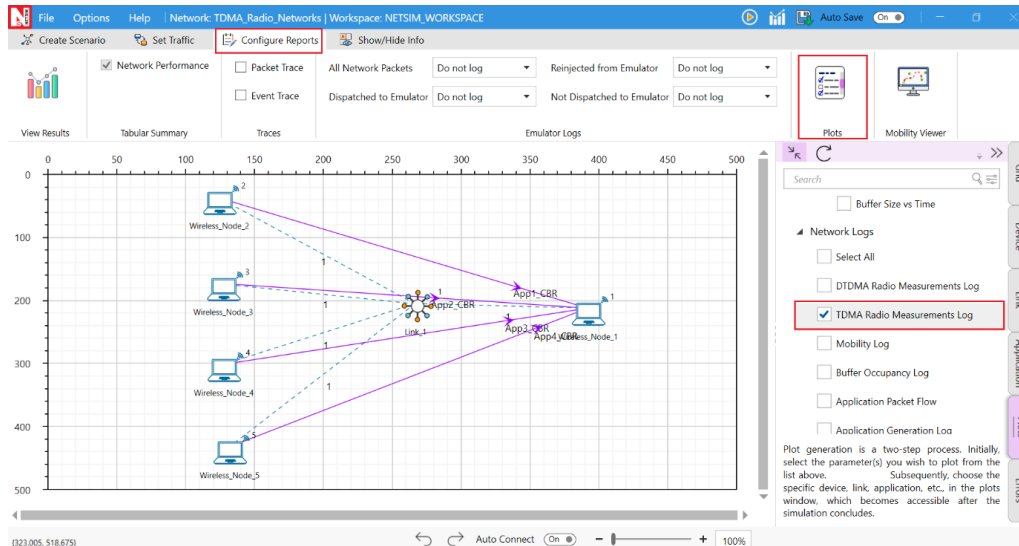


**Figure 3-1:** Enabling TDMA Radio Measurements Log file.

The TDMA Radio Measurements Log.csv file will contain the following information:

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

The log file can be accessed from the Simulations Results Window under the Logs as shown below:

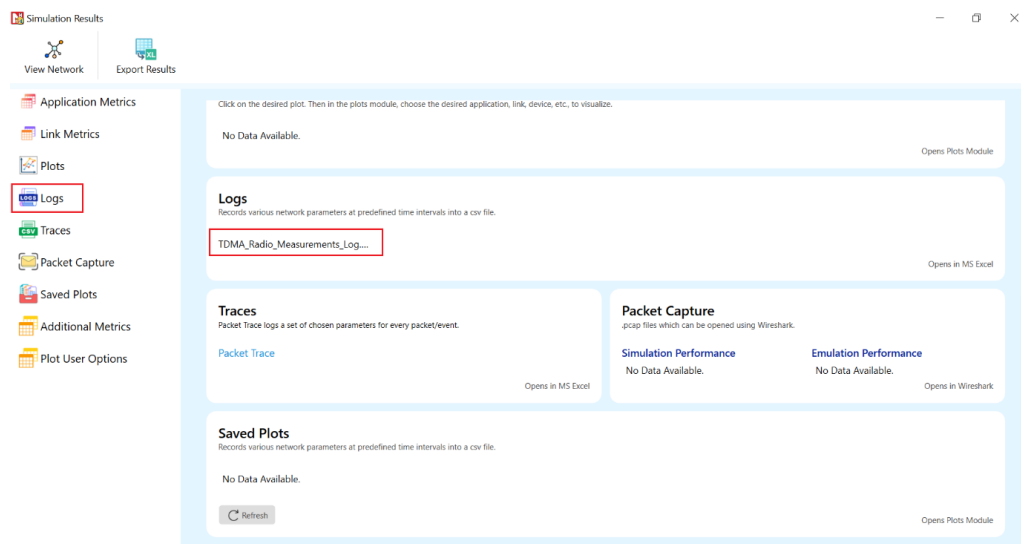


**Figure 3-2:** *TDMA Radio Measurements Log.csv* file highlighted in the Results window.

AutoSave

TDMA\_Radio\_Measurements.Lo...

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|    | A                      | B                | C             | D           | E                        | F           | G                   | H             | I             | J                  | K               |
|----|------------------------|------------------|---------------|-------------|--------------------------|-------------|---------------------|---------------|---------------|--------------------|-----------------|
|    | Time(ms)               | Transmitter name | Receiver Name | Distance(m) | Packet ID                | Packet Type | Control Packet Type | Tx Power(dBm) | Path Loss(dB) | Shadowing Loss(dB) | Fading Loss(dB) |
| 1  | 31.25 WIRELESS_NODE 2  | WIRELESS_NODE 1  | 320.319928    | 0           | Control_Packet AODV_RREQ | 13.0103     | 32.096173           | 1.048178      |               |                    |                 |
| 2  | 31.25 WIRELESS_NODE 2  | WIRELESS_NODE 3  | 136.702662    | 0           | Control_Packet AODV_RREQ | 13.0103     | 24.700034           | 0.680675      |               |                    |                 |
| 3  | 31.25 WIRELESS_NODE 2  | WIRELESS_NODE 4  | 264.875501    | 0           | Control_Packet AODV_RREQ | 13.0103     | 30.44533            | 2.569093      |               |                    |                 |
| 4  | 31.25 WIRELESS_NODE 2  | WIRELESS_NODE 5  | 395.65796     | 0           | Control_Packet AODV_RREQ | 13.0103     | 33.930892           | -3.162        |               |                    |                 |
| 5  | 62.5 WIRELESS_NODE 3   | WIRELESS_NODE 1  | 267.80107     | 0           | Control_Packet AODV_RREQ | 13.0103     | 30.54074            | 7.423647      |               |                    |                 |
| 6  | 62.5 WIRELESS_NODE 3   | WIRELESS_NODE 2  | 136.702662    | 0           | Control_Packet AODV_RREQ | 13.0103     | 24.700034           | -6.889        |               |                    |                 |
| 7  | 62.5 WIRELESS_NODE 3   | WIRELESS_NODE 4  | 128.183867    | 0           | Control_Packet AODV_RREQ | 13.0103     | 24.141162           | 4.890414      |               |                    |                 |
| 8  | 62.5 WIRELESS_NODE 3   | WIRELESS_NODE 5  | 258.95699     | 0           | Control_Packet AODV_RREQ | 13.0103     | 30.249004           | -4.809786     |               |                    |                 |
| 9  | 93.75 WIRELESS_NODE 4  | WIRELESS_NODE 1  | 279.189634    | 0           | Control_Packet AODV_RREQ | 13.0103     | 30.90248            | 6.330035      |               |                    |                 |
| 10 | 93.75 WIRELESS_NODE 4  | WIRELESS_NODE 2  | 264.875501    | 0           | Control_Packet AODV_RREQ | 13.0103     | 30.44533            | -3.761894     |               |                    |                 |
| 11 | 93.75 WIRELESS_NODE 4  | WIRELESS_NODE 3  | 128.183867    | 0           | Control_Packet AODV_RREQ | 13.0103     | 24.141162           | 6.687023      |               |                    |                 |
| 12 | 93.75 WIRELESS_NODE 4  | WIRELESS_NODE 5  | 130.801398    | 0           | Control_Packet AODV_RREQ | 13.0103     | 24.316742           | -4.271329     |               |                    |                 |
| 13 | 125 WIRELESS_NODE 5    | WIRELESS_NODE 1  | 340.697955    | 0           | Control_Packet AODV_RREQ | 13.0103     | 32.631885           | -8.098044     |               |                    |                 |
| 14 | 125 WIRELESS_NODE 5    | WIRELESS_NODE 2  | 395.65796     | 0           | Control_Packet AODV_RREQ | 13.0103     | 33.930892           | 2.294871      |               |                    |                 |
| 15 | 125 WIRELESS_NODE 5    | WIRELESS_NODE 3  | 258.95699     | 0           | Control_Packet AODV_RREQ | 13.0103     | 30.249004           | -4.153996     |               |                    |                 |
| 16 | 125 WIRELESS_NODE 5    | WIRELESS_NODE 4  | 130.801398    | 0           | Control_Packet AODV_RREQ | 13.0103     | 24.316742           | -6.719692     |               |                    |                 |
| 17 | 156.25 WIRELESS_NODE 1 | WIRELESS_NODE 2  | 320.319928    | 0           | Control_Packet AODV_RREP | 13.0103     | 32.096173           | 0.153006      |               |                    |                 |
| 18 | 187.5 WIRELESS_NODE 2  | WIRELESS_NODE 1  | 320.319928    | 0           | Control_Packet AODV_RREQ | 13.0103     | 32.096173           | 1.048178      |               |                    |                 |
| 19 | 187.5 WIRELESS_NODE 2  | WIRELESS_NODE 3  | 136.702662    | 0           | Control_Packet AODV_RREQ | 13.0103     | 24.700034           | 0.680675      |               |                    |                 |
| 20 | 187.5 WIRELESS_NODE 2  | WIRELESS_NODE 4  | 264.875501    | 0           | Control_Packet AODV_RREQ | 13.0103     | 30.44533            | 2.569093      |               |                    |                 |
| 21 | 187.5 WIRELESS_NODE 2  | WIRELESS_NODE 5  | 395.65796     | 0           | Control_Packet AODV_RREQ | 13.0103     | 33.930892           | -3.162        |               |                    |                 |
| 22 | 218.75 WIRELESS_NODE 3 | WIRELESS_NODE 1  | 267.80107     | 0           | Control_Packet AODV_RREQ | 13.0103     | 30.54074            | 7.423647      |               |                    |                 |
| 23 | 218.75 WIRELESS_NODE 3 | WIRELESS_NODE 2  | 136.702662    | 0           | Control_Packet AODV_RREQ | 13.0103     | 24.700034           | -6.889        |               |                    |                 |
| 24 | 218.75 WIRELESS_NODE 3 | WIRELESS_NODE 4  | 128.183867    | 0           | Control_Packet AODV_RREQ | 13.0103     | 24.141162           | 4.890414      |               |                    |                 |
| 25 | 218.75 WIRELESS_NODE 3 | WIRELESS_NODE 5  | 258.95699     | 0           | Control_Packet AODV_RREQ | 13.0103     | 30.249004           | -4.809786     |               |                    |                 |

TDMA\_Radio\_Measurements.Log

Pivot Table(Custom)

**Figure 3-3:** *TDMA Radio Measurements Log.csv* file

**Implementation Details and Assumptions** The log is written during each packet received at the physical layer (PHY\_IN). Hence the number of entries will be based on the number of packets received, by all nodes.

**NetSim plots** NetSim also provides TDMA radio measurement plots. Enabling the plots is explained in Section 2.8. Here is the plot showing the SNR vs. time for TDMA scenario with five nodes.

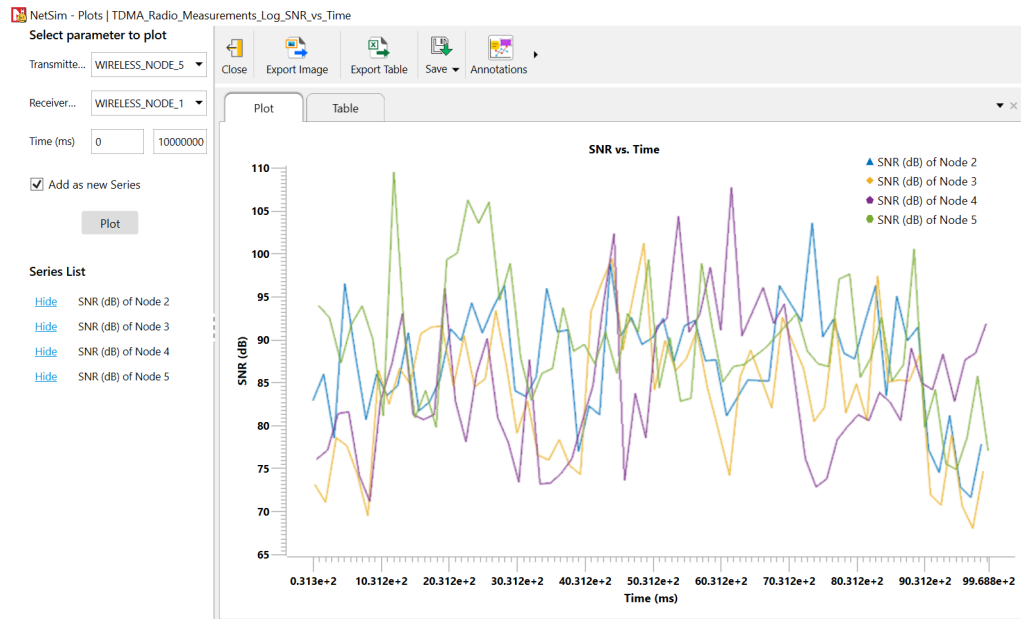


**Figure 3-4:** *SNR vs Time for TDMA scenario*

### 3.3 DTDMA

In TDMA, we simulate time-slotted networks; all nodes are synchronized in time and time is divided into slots. One or more packets can be sent in a slot. If the slot size is not an integral multiple of packet size, then the last packet is fragmented with the second fragment sent at the beginning of the next slot.

In DTDMA devices can leave / enter the network. For example, a network has 5 nodes. Assume that all nodes are present in the network initially. Node 1 uses slot 1, Node 2 uses slot 2 and so on till Node 5 uses slot 5. Let us say Node 2 leaves the network, then the frame is split into 4 slots. Node 1 uses slot 1, Node 3 uses slot 2, node 4 uses slot 3 and node 5 uses slot 4. The above example is based on demand-based slots allocation whereby devices having traffic to send will be allocated slots. Users can input up to 100 slots per device.

Apart from demand-based allocation, round robin slot allocation can also be chosen by the user. In the case of Round Robin scheduling, slots are allotted cyclically in increasing order of Node ID.

#### 3.3.1 DTDMA MAC

**Table 3-4:** *DTDMA MAC Config Parameters*

| Parameter          | Type   | Range  | Description                                                                                                                                             |
|--------------------|--------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| Slot Duration (ms) | Global | 1-100  | The time between the beginning of a slot and the end of that slot. The default Slot Duration value in GUI is 2ms                                        |
| Frame Duration (s) | Global | 1-1000 | The time between the beginning of a frame and the end of that frame. The default Frame Duration value in NetSim is 12s.                                 |
| Net Count          | Global | 1-128  | Multiple nets can be constructed by stacking several nets. The 7bit net number allows a network of up to 128 nets and the default value is 4 in NetSim. |

| Parameter                  | Type   | Range                                 | Description                                                                                                                                                                                                                                                                                                                                                                                                            |
|----------------------------|--------|---------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Net ID                     | Global | 1-26                                  | The Net Id determines the network address. The nets are numbered from 1-26. The default Net ID value in NetSim is 1.                                                                                                                                                                                                                                                                                                   |
| Guard Interval ( $\mu s$ ) | Global | 1-10000                               | It is the time gap between slots. The default Guard Interval value in NetSim is 100 $\mu s$ .                                                                                                                                                                                                                                                                                                                          |
| Slot Allocation Technique  | Global | Round Robin, Demand based, File based | Round Robin: The Scheduler serves equal portion to each queue in and in circular order, handling all processes without priority. Demand Based: Slots can be assigned on demand in dynamic TDMA. The Minimum and Maximum thresholds ensure fairness by preventing any node from monopolizing all slots or being completely starved. File Based: File based slot planner enables users to configure slot Planner Window. |
| Min Slot per Device        | Local  | 0-100                                 | It is the minimum number of allowable slots per device. The default value is 1 in NetSim.                                                                                                                                                                                                                                                                                                                              |
| Max Slot per Device        | Local  | 1-100                                 | It is the maximum number of allowable slots per device. The default value is 5 in NetSim.                                                                                                                                                                                                                                                                                                                              |
| Mix Packet Fragment        | Global | Enable, Disable                       | If this option is enabled, multiple packets/fragments can be aggregated and transmitted in a single slot, if the slot capacity is larger than the packet/fragment size. If this option is disabled, only one packet/fragment can be sent in a slot even if the slot capacity is larger than the packet/fragment size.                                                                                                  |
| MAC Address                | Fixed  | Auto generated                        | The MAC address is a unique value associated with a network adapter. This is also known as hardware address or physical address. This is a 12-digit hexadecimal number (48 bits in length).                                                                                                                                                                                                                            |

### 3.3.2 DTDMA PHY

**Table 3-5:** *DTDMA PHY Config Parameters*

| Parameter                  | Type      | Range                                       | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|----------------------------|-----------|---------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Bandwidth (KHz)            | Global    | 1-10000                                     | Represents the system bandwidth. The default bandwidth value in NetSim is 20MHz.                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Data symbol rate (kBd)     | Global    | 0-10000                                     | Baud rate for data transmission.                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Forward Error Correction   | Fixed     | TRUE                                        | Forward error correction enable/disable                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| TX power (W)               | Local     | 1-100                                       | It is the signal intensity of the transmitter. The default transmit power value is 20 W.                                                                                                                                                                                                                                                                                                                                                                                                                |
| Antenna Gain (dBi)         | Local     | 0-1000                                      | Represents the antenna's gain in dB scale. The default Antenna Gain value is 0 dBi.                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Antenna Height (m)         | Local     | 0-100                                       | Antenna height is only considered when using the following propagation models: Cost 231 Hata Urban, Cost 231 Hata Suburban, Hata Urban, Hata Suburban. These are propagation models used to model urban scenarios where the antenna height is an important parameter to compute the pathloss. When using these models, the antenna height represents the height of the antenna above the ground. Since these are urban scenarios, it is assumed that the nodes are always on the ground (i.e., $z=0$ ). |
| Receiver sensitivity (dBm) | Local     | 0 to -120                                   | Receiver Sensitivity is the lowest power at which the receiver can detect an RF signal and demodulate data. The default Receiver sensitivity value is -85 dBm                                                                                                                                                                                                                                                                                                                                           |
| Modulation Technique       | Local     | GMSK, QPSK, BPSK, 16QAM, 64QAM, CPM, MSK    | The chosen modulation technique impacts the PHY data rate. The default Modulation Technique is QPSK                                                                                                                                                                                                                                                                                                                                                                                                     |
| Coding Rate                | Local     | 1/2, 2/3, 3/4, 5/6                          | It states what portion of the total amount of information that is useful. The code rate is typically a fraction number, if the code rate is $k/n$ , for every $k$ bits of useful information, the coder totally generates $n$ bits of data.                                                                                                                                                                                                                                                             |
| PHY efficiency factor      | Local     | 0.01 to 1.00                                | A scaling factor (typically 0 to 1) that accounts for real-world PHY-layer overheads like pilot symbols, guard bands, and cyclic prefixes, reducing the ideal data rate to achievable throughput. Example: $\eta = 0.8$ means 80% of the theoretical rate is usable after overheads.                                                                                                                                                                                                                    |
| Slot Capacity(B)           | Fixed     | Auto-generated                              | The amount of data (in bytes) that can be transmitted during one TDMA time slot.                                                                                                                                                                                                                                                                                                                                                                                                                        |
| PHY rate(Mbps)             | Fixed     | Auto-generated                              | The effective data rate at the physical layer, calculated based on symbol rate, modulation, coding, and PHY efficiency.                                                                                                                                                                                                                                                                                                                                                                                 |
| Frequency Hopping          | Local     | ON/OFF                                      | Frequency Hopping switches a carrier among many frequency "channels", using a pseudorandom sequence. The number of channels is given by $c = (F_U - F_L)/BW$ , where $F_U$ is the upper frequency, $F_L$ is the lower frequency, and $BW$ is the bandwidth.                                                                                                                                                                                                                                             |
| Band                       | Local     | VHF, UHF, L-Band, S-Band, C-Band, Ku, K, Ka | Represents the RF band in which the devices communicate. The default band value is VHF                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Lower (MHz)                | Frequency | Local                                       | Depends on Band selection                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Upper (MHz)                | Frequency | Local                                       | Depends on Band selection                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

### 3.3.3 PHY Data Rate

The PHY Rate for DTDMA is calculated as

$$\text{SymbolPerSlot} = \text{SlotDuration(ms)} \times \text{DataSymbolRate(kBd)} \quad (2)$$

$$\text{Bits per Slot} = \text{Symbols per Slot} \times \text{Bits per Symbol} \quad (3)$$

$$\text{Bits per Slot} = \text{SymbolPerSlot} \times \text{ModulationOrder} \times \text{CodingRate} \times \text{PHYEfficiencyFactor} \quad (4)$$

$$\text{LinkPHYCapacity} = \text{PHY Rate(kbps)} = \frac{\text{BitsPerSlot}}{\text{SlotDuration(ms)}} \quad (5)$$

$$\text{LinkPHYCapacity} = \text{PHY EfficiencyFactor} \times \text{DataSymbolRate(kBd)} \times \text{ModulationOrder} \times \text{CodeRate} \quad (6)$$

**Table 3-6:** Example input settings for Modulation, CodeRate, DataSymbolRate and Bandwidth to get the desired PHY rate. The PHY rate is the radio link's capacity.

| Modulation Technique | Modulation Order | Code Rate | DataSymbolRate (kBd) | Bandwidth (KHz) | PHY Rate |
|----------------------|------------------|-----------|----------------------|-----------------|----------|
| QPSK                 | 2                | 1/2       | 32                   | 32              | 32 Kbps  |
| QPSK                 | 2                | 1/2       | 64                   | 64              | 64 Kbps  |
| 16-QAM               | 4                | 1/2       | 32                   | 32              | 64 Kbps  |
| QPSK                 | 2                | 1/2       | 128                  | 128             | 128 Kbps |
| 64-QAM               | 6                | 2/3       | 32                   | 32              | 128 Kbps |
| 16-QAM               | 4                | 3/4       | 333                  | 333             | 1 Mbps   |
| 64-QAM               | 6                | 5/6       | 200                  | 200             | 1 Mbps   |

Users must note that:

- Application throughput will always be less than or equal to the PHY Rate. The reasons are:
  - The slot allocation mechanism. Slots are not always allotted only to the transmitting nodes. Slots allotted to non-transmitting nodes in DTDMA consume “time” resources.
  - Propagation losses.
- If you turn off AODV and simulate using static route (for packets from source to destination) there will be no control packet overheads. If AODV is turned on time is spent in route discovery and hence the application throughput will be impacted
- The band (UHF, VHF, L-Band, S-band, C-band, Ka, Ku, K) chosen will not impact the PHY rate; it only has an impact on the propagation losses and in turn on the SINR.
- The PHY rate is unique to each transmitter since the Modulation and coding rate can be uniquely set at each node.

### 3.3.4 Waveform

The closest waveform NetSim's BPSK/QPSK/QAM model aligns with is a single-carrier signal using raised cosine pulse modulated to the carrier frequency via BPSK/QPSK/QAM.

NetSim does not explicitly differentiate between single-carrier, DSSS, and FHSS for non-fading or Rayleigh flat fading channels, as their performance is equivalent in these scenarios. Differences arise only when modeling jamming or frequency-selective fading, which NetSim does not currently model.

### 3.3.5 Pathloss and BER

Refer to the Propagation-Models documentation to understand the pathloss calculations, and the BER modelling.

FEC means forward error correction. If FEC is enabled the BER in the channel will reduce. This means a user will see a reduction in error packets and possibly a small increase in throughput. The impact of FEC cannot be seen when the

- BER is 0 (FEC cannot improve it further), or
- BER is very high i.e., close to 1 (the error rate is too high for FEC to correct)

The received power (at Receiver) calculation is done at the transmitter. If the computed receiver power is less than the Receive sensitivity no transmissions are attempted. Packets are simply dropped at the transmitter. This count is not marked in the metrics or in the trace.

### 3.3.6 PHY layer slot capacity

The amount of data that can be transmitted in a slot depends on the modulation technique, the coding rates, the data symbol rate and the slot time. All of these are user configurable parameters in the GUI.

$$\text{SlotCapacity[Bits]} = \text{SymbolsPerSlot} \times \text{BitsPerSymbol} \quad (7)$$

$$\text{SlotCapacity} = \frac{\text{SymbolsPerSecond}}{\text{SlotsPerSecond}} \times (\text{ModulationOrder} \times \text{CodingRate} \times \text{PHYEfficiencyFactor}) \quad (8)$$

$$\text{SlotCapacity} = (\text{DataSymbolRate} \times \text{SlotDuration}) \times (\text{ModulationOrder} \times \text{CodingRate} \times \text{PHYEfficiencyFactor}) \quad (9)$$

$$\text{SlotCapacity[Bytes]} = \frac{\lfloor \text{SlotCapacity} \rfloor}{8}$$

Post simulation, the data transmitted in a slot can be observed in the PHY Layer Payload column of the packet trace. The table below shows the slot capacity for various combinations of modulation techniques, coding rates and Data symbol rate with the slot duration fixed at 2 ms.

**Table 3-7:** Slot Capacity Calculation for Different Modulation Techniques, Coding Rates, and Data Symbol Rates

| Modulation Technique<br>Coding Rate | QPSK              |         |       | 16QAM |         |       | 64QAM |      |        |
|-------------------------------------|-------------------|---------|-------|-------|---------|-------|-------|------|--------|
|                                     | 1/2               | 2/3     | 3/4   | 1/2   | 2/3     | 3/4   | 1/2   | 2/3  | 3/4    |
| Data Symbol Rate (kBd)              | Slot Capacity (B) |         |       |       |         |       |       |      |        |
| 25                                  | 6.25              | 8.25    | 9.375 | 12.5  | 16.625  | 18.75 | 18.75 | 25   | 28.125 |
| 100                                 | 25                | 33.25   | 37.5  | 50    | 66.625  | 75    | 75    | 100  | 112.5  |
| 500                                 | 125               | 166.625 | 187.5 | 250   | 333.25  | 375   | 375   | 500  | 562.5  |
| 1000                                | 250               | 333.25  | 375   | 500   | 666.625 | 750   | 750   | 1000 | 1125   |

#### Example: Calculations

Modulation order for QPSK is 2, for 16-QAM is 4, and for 64-QAM is 6 and in these calculations PHY efficiency factor is assumed to be 1.

- For Data Rate Symbol of 25 kBd with coding rate of 1/2 and modulation QPSK

$$\text{SlotCapacity}(B) = \frac{(25 \times 2) \times (2 \times \frac{1}{2} \times 1)}{8} = 6.25 \text{ B}$$

- For Data Rate Symbol of 500 kBd with coding rate of 2/3 and modulation 16QAM,

$$\text{SlotCapacity}(B) = \frac{(500 \times 2) \times (4 \times \frac{2}{3} \times 1)}{8} = 333.33 \text{ B}$$

### 3.3.7 Demand based access

In the case of the Demand-Based Slot allocation technique, slots are allocated on demand. That is, slots are not wasted by allocating equal slots to all devices regardless of whether they have packets to transmit or not.

Instead, only the minimum number of slots as specified by min slot per device, are allocated to devices that do not have any demand. For devices with demand (that have packets in the buffer to transmit) an appropriately calculated number of slots between min and max slots per device is used for slot allocation.

### 3.3.8 DTDMA slot planner

Slot planner can be used to configure a predefined slot allocation pattern for the nodes in the network. Based on the configuration done, slots will be allocated to the devices during the simulation. Multiple/continuous slots can be allocated to the same node or to different nodes as per the requirement.

### 3.3.9 Configuring a Custom Error Model in DTDMA

Users can configure a custom error model in DTDMA within NetSim by using the SINR\_BER by Table via File option in the GUI. Follow these steps:

- Click on the wireless node, in the right-side panel, expand Interface 1 properties. Then, expand Physical layer properties.

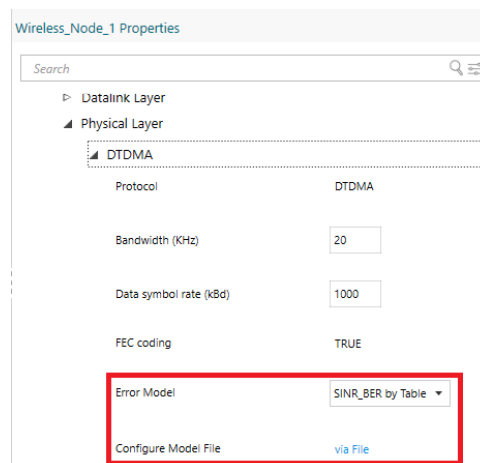


**Figure 3-5:** Configuring error model under physical layer of DTDMA

- In the Error Model dropdown menu, choose SINR\_BER by Table. Click on via file to open the SINR\_BER.csv file. This file contains two columns: SINR (dB) and BER with default values of SINR ranging from 0 to 15 dB with their corresponding BER values.

|   | A         | B        | C |
|---|-----------|----------|---|
| 1 | SINR (dB) | BER      |   |
| 2 | 0         | 4.00E-02 |   |
| 3 | 3         | 7.15E-03 |   |
| 4 | 6         | 2.66E-04 |   |
| 5 | 9         | 1.10E-05 |   |
| 6 | 12        | 4.81E-07 |   |
| 7 | 15        | 2.12E-09 |   |

**Figure 3-6:** *SINR\_BER.csv file*

- Enter the desired SINR and BER values in the table, ensuring that the SINR column is sorted in ascending order. Users can enter BER values in decimal format (e.g., 0.05) or scientific notation (e.g., 5E-02).
- Save the csv file and close.

SINR (Signal to Noise and Interference Ratio): Measured in decibels (dB). When no interference is present, this value represents the Signal-to-Noise Ratio (SNR).

BER (Bit Error Rate): The probability of bit errors at a given SINR level.

BER Lookup Rules:

- For SINR values between table entries: NetSim uses the BER corresponding to the next lower SINR value in the table.
- **Example:** If the table has entries for 5 dB and 6 dB, an SINR of 5.7 dB will use the BER value for 5 dB.
- For SINR values below the table's minimum: NetSim uses the BER corresponding to the lowest SINR value in the table.

**Example:** If the lowest table entry is 0 dB, an SINR of -2 dB will use the BER value for 0 dB.

- For a single-entry SINR table: If the table contains only one SINR value, NetSim applies the corresponding BER for all obtained SINR values.

**Example:** If the table contains only 5 dB, any SINR (whether higher or lower) will use the BER value for 5 dB.

### 3.3.10 DTDMA Radio Measurements Log

NetSim DTDMA Radio measurements csv log file records pathloss, shadowing loss, fading loss, received power, transmitted power, SNR. This log can be enabled by clicking on configure reports in top ribbon > Plots > DTDMA Radio Measurements log option under the Network Logs section as shown below:

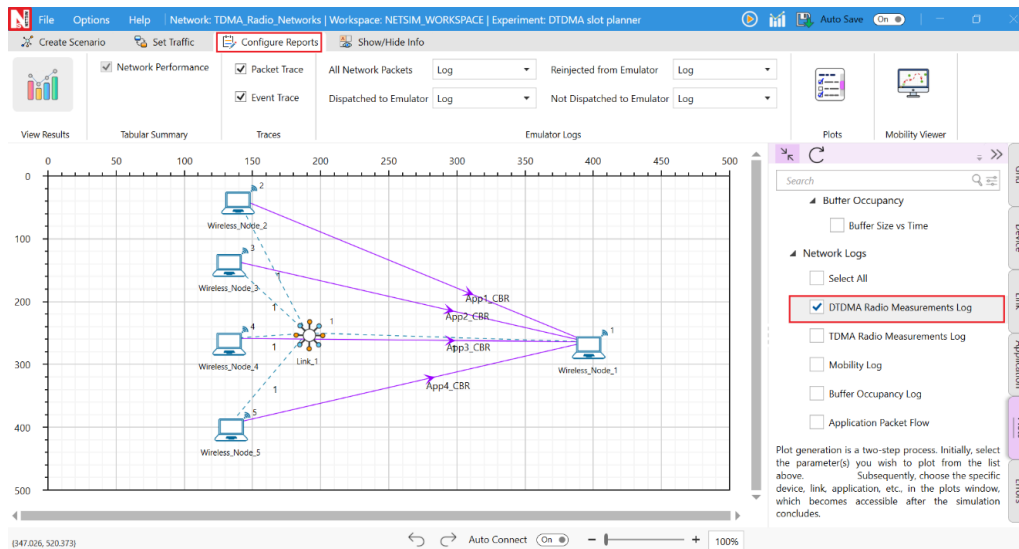


**Figure 3-7:** Enabling DTDMA Radio Measurements Log file

The DTDMA Radio Measurements Log.csv file will contain the following information:

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

The log file can be accessed from the Simulations Results Window under the Logs as shown below:

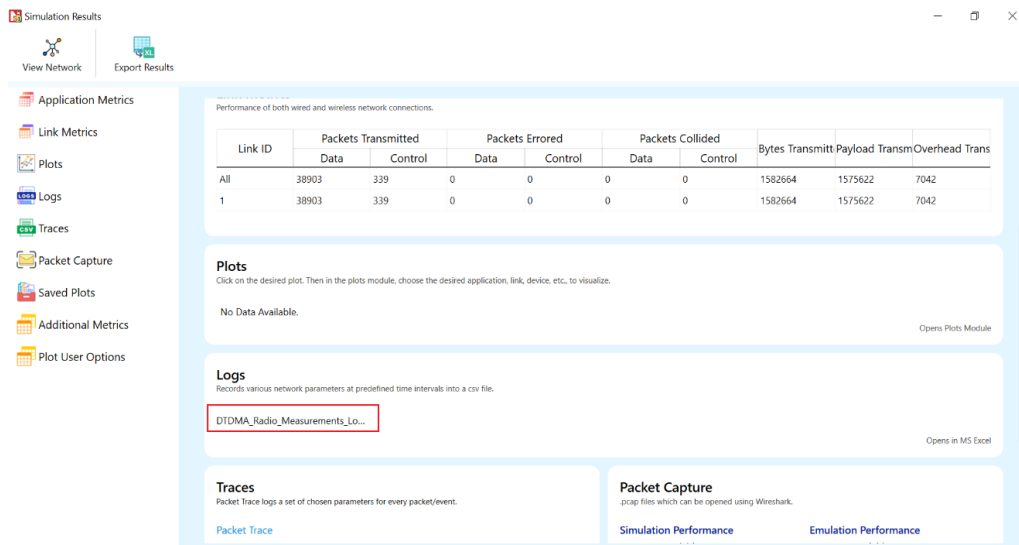


**Figure 3-8:** Opening DTDMA Radio Measurements log.csv from the Results window.

The screenshot shows the DTDMA\_Radio\_Measurements\_10... log file in Excel. The table contains columns for Time(ms), Transmitter Name, Receiver Name, Distance(m), Packet ID, Packet Type, Control Packet Type, Tx Power(dBm), Path Loss(dB), Shadowing Loss(dB), Fading Loss(dB), and Tot. The data is organized into rows, with the first row being a header and subsequent rows containing measurement data for various nodes and packet types.

|    | A        | B                | C               | D           | E         | F                       | G                   | H             | I             | J                  | K               |     |
|----|----------|------------------|-----------------|-------------|-----------|-------------------------|---------------------|---------------|---------------|--------------------|-----------------|-----|
|    | Time(ms) | Transmitter Name | Receiver Name   | Distance(m) | Packet ID | Packet Type             | Control Packet Type | Tx Power(dBm) | Path Loss(dB) | Shadowing Loss(dB) | Fading Loss(dB) | Tot |
| 1  | 2.1      | WIRELESS_NODE_3  | WIRELESS_NODE_3 | 294.429531  | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 31.364122     | -4.39958           | 0               |     |
| 2  | 2.1      | WIRELESS_NODE_3  | WIRELESS_NODE_3 | 99.424806   | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 21.934389     | -1.129157          | 0               |     |
| 3  | 2.1      | WIRELESS_NODE_3  | WIRELESS_NODE_3 | 125.140924  | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 23.932481     | 2.294871           | 0               |     |
| 4  | 2.1      | WIRELESS_NODE_3  | WIRELESS_NODE_3 | 261.560133  | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 30.335925     | 4.827517           | 0               |     |
| 5  | 4.2      | WIRELESS_NODE_4  | WIRELESS_NODE_4 | 263.851596  | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 30.411689     | 6.421514           | 0               |     |
| 6  | 4.2      | WIRELESS_NODE_4  | WIRELESS_NODE_4 | 224.446455  | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 29.006749     | -3.162             | 0               |     |
| 7  | 4.2      | WIRELESS_NODE_4  | WIRELESS_NODE_4 | 125.140924  | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 23.932481     | -4.809786          | 0               |     |
| 8  | 4.2      | WIRELESS_NODE_4  | WIRELESS_NODE_4 | 136.423178  | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 24.682257     | -1.267769          | 0               |     |
| 9  | 6.3      | WIRELESS_NODE_2  | WIRELESS_NODE_2 | 345.084919  | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 32.743014     | 0.565094           | 0               |     |
| 10 | 6.3      | WIRELESS_NODE_2  | WIRELESS_NODE_2 | 99.424806   | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 21.934389     | -5.760419          | 0               |     |
| 11 | 6.3      | WIRELESS_NODE_2  | WIRELESS_NODE_2 | 224.446455  | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 29.006749     | -8.098044          | 0               |     |
| 12 | 6.3      | WIRELESS_NODE_2  | WIRELESS_NODE_2 | 360.801485  | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 33.12986      | -6.719692          | 0               |     |
| 13 | 8.4      | WIRELESS_NODE_5  | WIRELESS_NODE_5 | 293.062339  | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 31.324287     | -4.271329          | 0               |     |
| 14 | 8.4      | WIRELESS_NODE_5  | WIRELESS_NODE_5 | 360.801485  | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 33.12986      | 6.350718           | 0               |     |
| 15 | 8.4      | WIRELESS_NODE_5  | WIRELESS_NODE_5 | 261.560133  | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 30.335925     | -9.809533          | 0               |     |
| 16 | 8.4      | WIRELESS_NODE_5  | WIRELESS_NODE_5 | 136.423178  | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 24.682257     | 0.560108           | 0               |     |
| 17 | 21       | WIRELESS_NODE_1  | WIRELESS_NODE_1 | 294.429531  | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 31.364122     | -1.932905          | 0               |     |
| 18 | 23.1     | WIRELESS_NODE_3  | WIRELESS_NODE_3 | 294.429531  | 1         | App2_CBR                |                     | 43.0103       | 31.364122     | -4.39958           | -0.524723       |     |
| 19 | 33.6     | WIRELESS_NODE_3  | WIRELESS_NODE_3 | 294.429531  | 1         | App2_CBR                |                     | 43.0103       | 31.364122     | -4.39958           | -2.658518       |     |
| 20 | 35.7     | WIRELESS_NODE_4  | WIRELESS_NODE_4 | 263.851596  | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 30.411689     | 6.421514           | 8.848884        |     |
| 21 | 35.7     | WIRELESS_NODE_4  | WIRELESS_NODE_4 | 224.446455  | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 29.006749     | -3.162             | -0.690854       |     |
| 22 | 35.7     | WIRELESS_NODE_4  | WIRELESS_NODE_4 | 125.140924  | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 23.932481     | -4.809786          | -5.413261       |     |
| 23 | 35.7     | WIRELESS_NODE_4  | WIRELESS_NODE_4 | 136.423178  | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 24.682257     | -1.267769          | 4.23799         |     |
| 24 | 37.8     | WIRELESS_NODE_2  | WIRELESS_NODE_2 | 345.084919  | 0         | Control_Packet DSR_RREQ |                     | 43.0103       | 32.743014     | 0.565094           | -0.310732       |     |

**Figure 3-9:** DTDMA Radio Measurements log.csv file

**Implementation Details and Assumptions** The log is written during each packet received at the physical layer (PHY IN). Hence the number of entries will be based on the number of packets received, by all nodes.

**NetSim plots** NetSim also provides DTDMA radio measurement plots. Enabling the plots is explained in Section 2.8. Here is the plot showing the pathloss vs. time for a DTDMA scenario with five nodes.

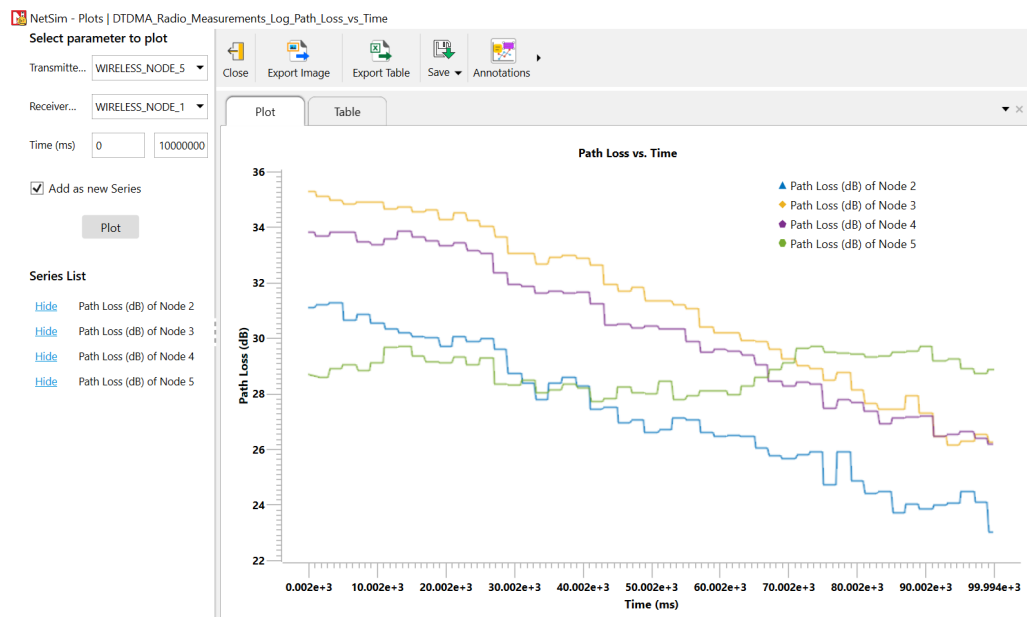


Figure 3-10: Pathloss vs Time for DTDMA scenario

### 3.4 Configuring applications between bridge nodes

Routing protocols in MANETs are supported only for single MANETs. If applications need to be configured between bridge nodes (to connect multiple MANETs) static routing needs to be enabled between the bridge nodes. An example scenario and its configuration are shown below.

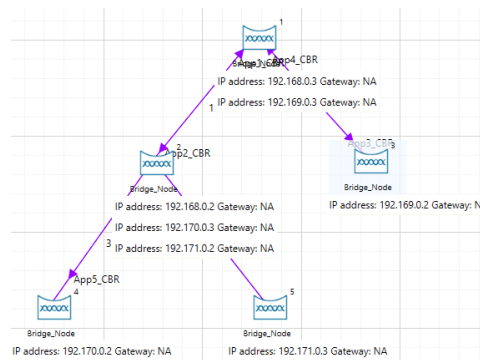


Figure 3-11: An example scenario with 5 bridge nodes and traffic configured to flow between the bridge nodes.

To set static routes in the bridge nodes:

- Right-click on the bridge node, click on Open Properties in new window.
- Click on Network Layer Enable – Static IP Route, then click on Configure Static IP Route and set the properties as per the screenshot below. Click on Add and then click on OK.
- Static route settings for the 5 bridge nodes are shown below.

Static IP Routing Configuration

Network Based **Node Based**

Network Destination: 192.171.0.3 Gateway: 192.168.0.3

Subnet Mask: 255.255.255.255 Metrics: 1

Interface ID: 1

Add Reset Remove

| <input type="checkbox"/> | Network Destination ▼ | Subnet Mask ▼   | Gateway ▼   | Metrics |
|--------------------------|-----------------------|-----------------|-------------|---------|
| <input type="checkbox"/> | 192.169.0.2           | 255.255.255.255 | 192.169.0.2 |         |
| <input type="checkbox"/> | 192.168.0.3           | 255.255.255.255 | 192.168.0.3 |         |
| <input type="checkbox"/> | 192.170.0.3           | 255.255.255.255 | 192.168.0.3 |         |
| <input type="checkbox"/> | 192.171.0.3           | 255.255.255.255 | 192.168.0.3 |         |

OK Cancel

Static IP Routing Configuration

Network Based **Node Based**

Network Destination: 192.170.0.2 Gateway: Text Field can not be empty

Subnet Mask: 255.255.255.255 Metrics: 1

Interface ID: 1

Add Reset Remove

| <input type="checkbox"/> | Network Destination ^ | Subnet Mask ▼   | Gateway ▼   | Metrics |
|--------------------------|-----------------------|-----------------|-------------|---------|
| <input type="checkbox"/> | 192.168.0.2           | 255.255.255.255 | 192.168.0.2 |         |
| <input type="checkbox"/> | 192.169.0.3           | 255.255.255.255 | 192.168.0.2 |         |
| <input type="checkbox"/> | 192.170.0.2           | 255.255.255.255 | 192.170.0.2 |         |
| <input type="checkbox"/> | 192.171.0.2           | 255.255.255.255 | 192.171.0.2 |         |

OK Cancel

Static IP Routing Configuration

Network Based **Node Based**

Network Destination: 192.169.0.3 Gateway: 192.168.0.2

Subnet Mask: 255.255.255.255 Metrics: 1

Interface ID: 1

Add Reset Remove

| <input type="checkbox"/> | Network Destination ▼ | Subnet Mask ▼   | Gateway ▼   | Metrics |
|--------------------------|-----------------------|-----------------|-------------|---------|
| <input type="checkbox"/> | 192.168.0.2           | 255.255.255.255 | 192.168.0.2 |         |
| <input type="checkbox"/> | 192.169.0.3           | 255.255.255.255 | 192.168.0.2 |         |

OK Cancel

Static IP Routing Configuration

Network Based **Node Based**

Network Destination: 192.168.0.3 Gateway: 192.170.0.3

Subnet Mask: 255.255.255.255 Metrics: 1

Interface ID: 1

Add Reset Remove

| <input type="checkbox"/> | Network Destination ▼ | Subnet Mask ▼   | Gateway ▼   | Metrics |
|--------------------------|-----------------------|-----------------|-------------|---------|
| <input type="checkbox"/> | 192.170.0.3           | 255.255.255.255 | 192.170.0.3 |         |
| <input type="checkbox"/> | 192.171.0.3           | 255.255.255.255 | 192.170.0.3 |         |
| <input type="checkbox"/> | 192.168.0.3           | 255.255.255.255 | 192.170.0.3 |         |

OK Cancel

Static IP Routing Configuration

Network Based Node Based

Network Destination: 192.171.0.3 Gateway: 192.168.0.3

Subnet Mask: 255.255.255.255 Metrics: 1

Interface ID: 1

Add Reset Remove

|                          | Network Destination | Subnet Mask     | Gateway     | Metrics |
|--------------------------|---------------------|-----------------|-------------|---------|
| <input type="checkbox"/> | 192.168.0.3         | 255.255.255.255 | 192.168.0.3 |         |
| <input type="checkbox"/> | 192.170.0.3         | 255.255.255.255 | 192.168.0.3 |         |
| <input type="checkbox"/> | 192.171.0.3         | 255.255.255.255 | 192.168.0.3 |         |

OK Cancel

**Figure 3-12:** Static route settings at all 5 bridge nodes in serial order (right to left followed by top to bottom) from 1 to 5. Since these nodes are connected to multiple nodes, static routes should be configured in all interfaces.

### 3.5 Jammer

NetSim DTDMA module features a single-band jammer that can be used to block transmissions in the network. It does not take part in any communication like regular nodes and is modelled as an interference source - it generates interference in the wireless medium. This interference then leads to a lower received SINR which can lead to packet errors.

#### Jammer On/Off Status

- Jammer On (s): The simulation time at which the Jammer becomes active, and interference is introduced in the network.
- Jammer Off (s): The simulation time at which the Jammer becomes inactive and stops interference.

In NetSim, right-click on the Jammer device and open Properties in a new window. Under the Jammer Status Profile, the Jammer On and Jammer Off times can be configured. The default values are:

Jammer On = 0 seconds

Jammer Off = 1000000 seconds

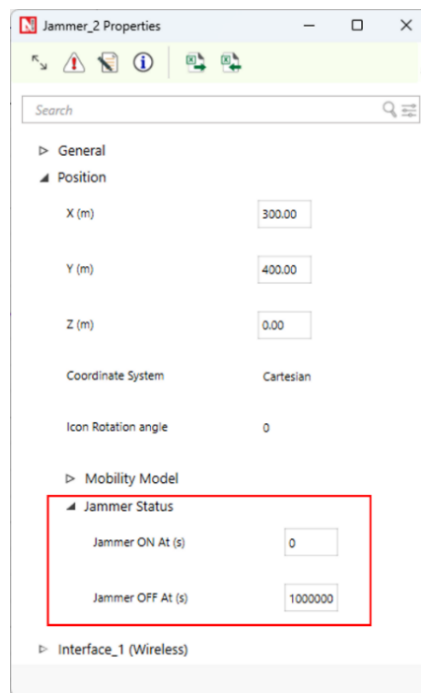


**Figure 3-13:** *Jammer properties*

Users may specify multiple On and Off times separated by commas. For example:

- Jammer On - 0, 20
- Jammer Off - 10, 50

In this case, the Jammer will be active from 0s to 10s, inactive between 10s and 20s, active again from 20s to 50s, and inactive thereafter.

Simulation results and plots will capture the effect of interference only during the periods when the Jammer is active. For example, if Jammer On = 0s and Jammer Off = 10s, with a total simulation time of 100s, interference will be observed only in the interval 0s to 10s.

### Jammer Range

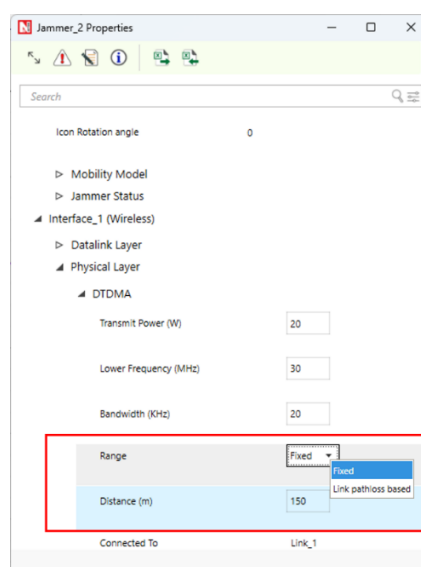


**Figure 3-14:** *Jammer properties*

The coverage of the Jammer can be configured using the Range parameter in the Jammer properties. Two options are available:

### 1. Fixed Range

- The Jammer's range is set to a fixed distance (in meters).
- The value is specified in the Distance (m) field.
- Any node within this distance is affected by the Jammer's interference.

### 2. Link Pathloss Based

- The Jammer's range is determined using the propagation model configured for the wireless medium, in the same way as other wireless devices in the network.
- Interference depends on the pathloss and channel conditions between the Jammer and the target node.

## Jammer Interference

When the Jammer is active, it adds interference at the receiver. This lowers the Signal-to-Interference-plus-Noise Ratio (SINR) and may result in packet errors. The interference depends on three factors:

### 1. Transmit power

The configured transmit power of the Jammer sets the maximum strength of interference.

### 2. Frequency and bandwidth

- The Jammer operates in a channel defined by its lower frequency and bandwidth.
- The transmitter also operates on its own frequency band.
- Interference occurs only if the two bands overlap.
- If the overlap is partial, only that fraction of the Jammer's power is considered.

Overlap bandwidth is given by:

$$BW_{overlap} = \max(0, \min(F_j^{end}, F_t^{end}) - \max(F_j^{start}, F_t^{start})) \quad (10)$$

where:

- $F_j^{start}$  = Jammer lower frequency
- $F_j^{end}$  = Jammer lower frequency + Jammer bandwidth
- $F_t^{start}$  = transmitter lower frequency (or carrier frequency, if defined)
- $F_t^{end}$  = transmitter lower frequency + transmitter bandwidth
- $BW_{overlap}$  = the portion of spectrum common to both Jammer and transmitter bands

If  $BW_{overlap} \leq 0$ , the two bands do not overlap, and no interference is applied.

### 3. Range model

- Fixed range
- Pathloss based

## Interference power

The Jammer's contribution to interference at the receiver is calculated as:

$$\text{Interference Power}_j = J_{rx}^{Power} \times \frac{BW_{overlap}}{BW_{tx}} \quad (11)$$

where:

- $J_{rx}^{Power}$  = Jammer power at the receiver (depends on Jammer transmit power and the range model used).
- $BW_{overlap}$  = the portion of the spectrum where the Jammer's frequency band overlaps with the transmitter's frequency band.
- $BW_{tx}$  = the transmitter's total bandwidth.

### Fixed Range:

If the Jammer range model is fixed, the configured transmit power of the Jammer is taken directly as the received power for interference calculations at any node located within the specified range.

- Transmitter lower frequency  $F_t^{start} = 30.000$  MHz
- Transmitter bandwidth  $BW_{tx} = 0.10$  MHz =  $F_t^{end} = 30.100$  MHz
- Jammer transmit power = 20 W = 43 dBm

**Example 1:** Partial overlap (Jammer  $BW_j = 0.02$  MHz)

Jammer lower frequency  $F_j^{start} = 30.000$  MHz

Jammer bandwidth  $BW_j = 0.02$  MHz =  $F_j^{end} = 30.020$  MHz

Overlap computation:

$$BW_{overlap} = \min(30.020, 30.100) - \max(30.000, 30.000) = 0.020 \text{ MHz}$$

Overlap ratio:

$$\frac{BW_{overlap}}{BW_{tx}} = \frac{0.020}{0.100} = 0.2$$

Fixed range model (receiver within configured distance):

$$Rx_{Power}^j = 43 \text{ dBm}$$

$$\text{InterferencePower}_{dBm} = 43 \times 0.2 = 8.6 \text{ dBm}$$

**Example 2:** Full overlap (Jammer  $BW_j = 0.10$  MHz)

Jammer lower frequency  $F_j^{start} = 30.000$  MHz

Jammer bandwidth  $BW_j = 0.10$  MHz =  $F_j^{end} = 30.100$  MHz

Overlap computation:

$$BW_{overlap} = \min(30.100, 30.100) - \max(30.000, 30.000) = 0.100 \text{ MHz}$$

Overlap ratio:

$$\frac{BW_{overlap}}{BW_{tx}} = \frac{0.100}{0.100} = 1$$

Fixed range model (receiver within configured distance):

$$Rx_{Power}^j = 43 \text{ dBm}$$

$$\text{InterferencePower}_{dBm} = 43 \times 1 = 43 \text{ dBm}$$

In the pathloss-based model, the Jammer's received power at the node is determined using the propagation model, and this value is then used in the interference power calculation.

### 3.5.1 Jammer PHY Properties

**Table 3-8:** *Jammer PHY properties*

| Parameter             | Type  | Range                         | Description                                                                                                                                                                                                  |
|-----------------------|-------|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Transmit Power (W)    | Local | 1–100                         | Configured transmit power of the Jammer. Default is 20 W. Used as Jammer power (fixed range) or input to propagation model (pathloss-based).                                                                 |
| Lower Frequency (MHz) | Local | 1-1000000                     | Minimum frequency at which the Jammer operates.                                                                                                                                                              |
| Bandwidth (kHz)       | Local | 1– 100000                     | Jammer operating bandwidth. Interference is applied only if overlap exists with the transmitter's band.                                                                                                      |
| Range                 | Local | Fixed / Pathloss-based        | Determines how the Jammer range is applied. In fixed range, all receivers within the specified distance are affected. In pathloss-based mode, received jammer power is computed using the propagation model. |
| Distance (m)          | Local | 1– 1000000                    | Applicable only for Fixed range model. Specifies the maximum distance up to which the Jammer is effective.                                                                                                   |
| Antenna Model         | Local | Omnidirectional / Directional | Defines the antenna pattern used for interference. Default is omnidirectional.                                                                                                                               |
| Antenna Height (m)    | Local | 0–100                         | Height of the Jammer antenna above ground. Considered only when propagation models (e.g., Hata, COST-231) require antenna height.                                                                            |
| Antenna Gain (dB)     | Local | 0–1000                        | Gain of the Jammer antenna, in dB scale. Default is 0 dB.                                                                                                                                                    |

### 3.6 Node Join / Leave

- Node join(s): It is the time at which the node joins the network.
- Node leave (s): It is the time at which the node leaves the network.

In NetSim, right-click on a Wireless Node and open properties in a new window. Under the Position in Node Join Profile, we have Node Join and Node Leave options with default values as shown below.

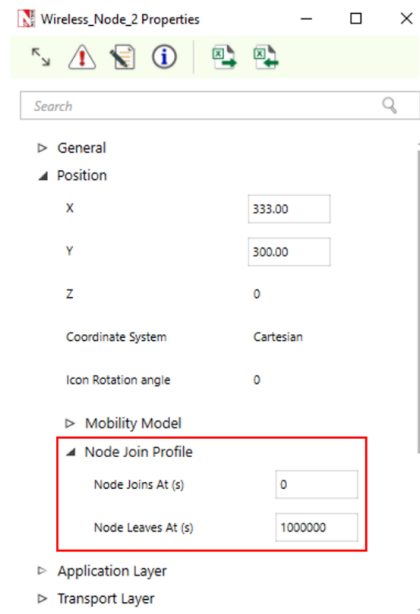


**Figure 3-15:** Node Join Profile window for Wireless Node

With default values, the node joins at 0 sec and leaves at 1000000 sec. Users can provide multiple inputs for Node join and Node leaves values separated by comma as shown below:

Node join - 0, 10

Node leave - 5, 100

In this case, the node joins the network at 0s and leaves at 5s and the node joins the network again at 10s and leaves at 100s.

Plots will be generated only for the period in which the node is present in the network. For example, if node join = 0s, node leave = 5s, and if the simulation time = 100s, the plots will be generated only for 0s to 5s.

### 3.6.1 Dynamic slot allocation

The dynamic TDMA protocol, when running the round robin algorithm, recalculates slot allocation when nodes join or leave. This recalculation occurs at the start of every frame, with the frame duration being a user input (e.g., 10 s). If a node leaves in the middle of a frame, slots will continue to be allocated to that node until the frame ends. The allocation will change in the subsequent frame.

## 3.7 Mobility Models in NetSim

Mobility models can be used to model movement of the wireless nodes. The mobility models provided in NetSim are:

1. **Random Walk mobility model:** It is a simple mobility model based on random directions and speeds.
2. **Random Waypoint Mobility Model:** It includes pause time between changes in direction and/or speed.
3. **Group mobility:** It is a model which describes the behavior of wireless nodes as they move together i.e., the wireless nodes having common group id will move together.
4. **Pedestrian Mobility Model:** This model is applicable to each node (local parameter), and the configuration parameters are:

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

In this model it is assumed that the pedestrian stops at traffic lights. The stop probability represents the probability of encountering a traffic light. This is checked for every Calculation interval. Once stopped, the pedestrian waits for a duration equal to stop duration for the light to turn green. A new direction is chosen randomly after every stop with  $\theta$  (angle between new direction and current direction) taking values of 0, 90, 180, 270. These  $\theta$  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 every stop with  $Min\_speed \leq Speed \leq Max\_Speed$ . The maximum number of stops and starts is 10.

5. **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 per NetSim Mobility File format, described in the MANET Technology Library document.

### 3.8 Propagation Models

The various bands supported in DTDMA, and associated frequency ranges are provided in the table below:

**Table 3-9:** Bands supported in DTDMA

| Band   | Min Freq | Max Freq |
|--------|----------|----------|
| VHF    | 30MHz    | 300MHz   |
| UHF    | 300MHz   | 3000MHz  |
| L-Band | 1000MHz  | 2000MHz  |
| S-Band | 2000MHz  | 4000MHz  |
| C-Band | 4000MHz  | 8000MHz  |
| Ku     | 12000MHz | 18000MHz |
| K      | 18000MHz | 27000MHz |
| Ka     | 26000MHz | 40000MHz |

The table below shows the recommended applicability of different pathloss models for the various DTDMA bands.

**Table 3-10:** Applicability of pathloss models for the various DTDMA bands.

| Pathloss Models         | Min            | Max     | VHF | UHF | L-Band | S-Band/C-Band |
|-------------------------|----------------|---------|-----|-----|--------|---------------|
| Friis Free Space        | For all ranges |         | Yes | Yes | Yes    | Yes           |
| Log Distance            | For all ranges |         | Yes | Yes | Yes    | Yes           |
| COST 231 HATA Urban     | 1500MHz        | 2000MHz | Yes | Yes | Yes    | No            |
| COST 231 HATA Sub Urban | 1500MHz        | 2000MHz | No  | Yes | Yes    | No            |
| HATA Urban              | 150MHz         | 1500MHz | Yes | Yes | Yes    | No            |
| HATA Suburban           | 150MHz         | 1500MHz | Yes | Yes | Yes    | No            |
| Indoor Office           | 900MHz         | 100GHz  | No  | Yes | Yes    | Yes           |
| Indoor Factory          | 900MHz         | 100GHz  | No  | Yes | Yes    | Yes           |
| Indoor Home             | 900MHz         | 100GHz  | Yes | Yes | Yes    | Yes           |
| Two Ray                 | For all ranges |         | Yes | Yes | Yes    | Yes           |

### 3.9 Antenna Models

NetSim's TDMA library supports Omnidirectional antennas, sector antennas and external antenna patterns. The differences between the models lie in the antenna gain values that vary as a function of transmitter-receiver direction in two dimensions. A transmitter or receiver antenna provides a gain value with respect to every other point in space. For a given transmission, the gains of both the transmitter and receiver are taken into account.

#### Omnidirectional Antenna

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

#### Sector Antenna (2D Parabolic Pattern)

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

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

where,

$A_m$  is the front to back ratio (i.e., the ratio of power gain between the front and rear of a directional antenna). This is a user input with a default setting of 30 dB.

$\varphi$  is the angle formed between the direction of interest (i.e., the line connecting the transmitter and the receiver) and the antenna's boresight direction (azimuth angle).

$\varphi_{3dB}$  is the 3 dB, or half power, beam width of the antenna.

The sector antenna gain is given by the expression

$$A_E(\varphi, \theta) = G_{E,max} - \min\{-[A_{E,H}(\varphi) + A_{E,V}(\theta)], A_m\} \quad (13)$$

where,

$A_{E,V}(\theta)$  is currently 0 dB, and is a parameter reserved for future use to include the vertical radiation pattern of the antenna, and

$G_{E,max}$  is the maximum directional gain of the radiation element (in dB) i.e., the gain along the antenna boresight; this parameter is a user input and the default value is 8 dBi.

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

Angle in NetSim is defined to start at 0 from the positive X-axis. The unit for angle is degrees.

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

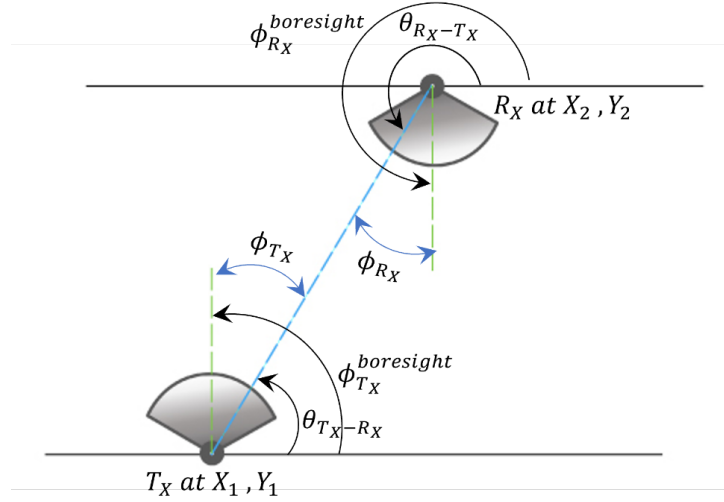


**Figure 3-16:** The illustration shows a transmitter at  $X_1, Y_1$  and a receiver at  $X_2, Y_2$ . The green lines represent the boresight azimuth direction of each antenna. The blue line is the line joining the transmitter and the receiver.  $\phi_{tx}$  (and  $\phi_{rx}$ ) are the angles formed between the line connecting the transmitter and the receiver and the transmit antenna's (and receive antennas respectively) boresight direction.

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

We know that

$$\theta_{T_X-R_X} = \tan^{-1} \left( \frac{y_2 - y_1}{x_2 - x_1} \right) \quad (14)$$

and clearly

$$\theta_{R_X-T_X} = \pi + \theta_{T_X-R_X} \quad (15)$$

$$\phi_{T_X} = \phi_{T_X}^{boresight} - \theta_{T_X-R_X} \quad (16)$$

$$\phi_{R_X} = \phi_{R_X}^{boresight} - \theta_{R_X-T_X} \quad (17)$$

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

$$A_{T_X}(\phi) = -\min \left[ 12 \left( \frac{\phi_{T_X}}{\phi_{3dB}} \right)^2, A_m \right] \quad (18)$$

$$A_{R_X}(\phi) = -\min \left[ 12 \left( \frac{\phi_{R_X}}{\phi_{3dB}} \right)^2, A_m \right] \quad (19)$$

$$T_X \text{ Gain} = G_{E,max} - \min [-(A_{T_X}(\phi)), A_m] \quad (20)$$

$$R \text{ Gain} = G_{E,max} - \min [-(A_{R_X}(\phi)), A_m] \quad (21)$$

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

### External Antenna Pattern (CSV File)

NetSim supports the use of external antenna patterns, where the gain values are explicitly provided by the user in a CSV file. This file must contain gain values corresponding to azimuth angles Phi ( $\varphi$ ) ranging

from 0 to 360 degrees. This method allows the use of measured or predefined antenna patterns in the simulation.

During simulation:

The Phi angle between the transmitter and receiver is computed based on their X-Y coordinates and antenna orientation directions as explained above in the 2D Parabolic pattern.

The gain value is then determined by looking up the CSV file.

The gain corresponding to the highest Phi ( $\varphi$ ) in the table that is less than or equal to the calculated Phi is selected.

This process is applied separately for both the transmitter and the receiver.

An example of gain values at different Phi angles is shown below.

| Phi | AntennaGain |
|-----|-------------|
| 0   | 8           |
| 1   | 8           |
| 2   | 7.99        |
| 3   | 7.97        |
| 4   | 7.95        |
| 5   | 7.93        |
| 6   | 7.9         |
| 7   | 7.86        |
| 8   | 7.82        |
| 9   | 7.77        |
| 10  | 7.72        |
| 11  | 7.66        |
| 12  | 7.59        |
| 13  | 7.52        |
| 14  | 7.44        |
| 15  | 7.36        |
| 16  | 7.27        |
| 17  | 7.18        |
| 18  | 7.08        |
| 19  | 6.97        |
| 20  | 6.86        |
| 21  | 6.75        |
| 22  | 6.63        |

**Figure 3-17:** *Antenna Gain(dB) vs Phi Angle*

Above figure shows an external antenna pattern defined with a 1-degree step size. Users can define antenna patterns using any arbitrary step size.

### 3.9.1 Limitations

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

## 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 DTDMA

#### 4.1.1 DTDMA Slot Planner

Open NetSim and Select **Examples** ▸ **TDMA Radio Networks** ▸ **DTDMA** ▸ **DTDMA Slot Planner** then click on the tile in the middle panel to load the example as shown in Figure 4-1.

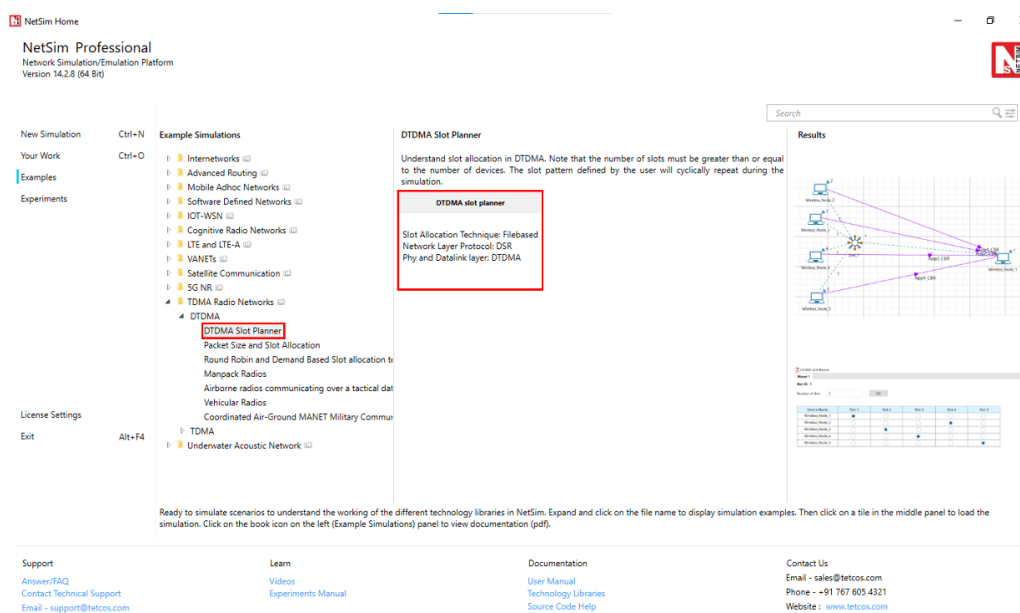


**Figure 4-1:** List of scenarios for the example of DTDMA Slot Planner

The following network diagram illustrates what the NetSim UI displays when you open the example configuration file DTDMA-Slot-Planner as shown below.

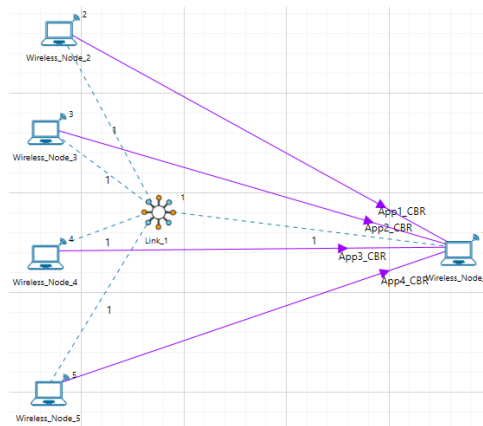


**Figure 4-2:** Network set up for studying the DTDMA Slot Planner

Settings done in the Network:

- Grid length: 1000m × 500m from grid setting property panel on the right. This needs to be done before any device is placed on the grid.
- In the wireless nodes DTDMA protocol is set in Interface\_1 (Wireless) datalink layer. To set any properties in the node, click on the node, expand the device property panel on the right side, and change the properties as mentioned in the below steps

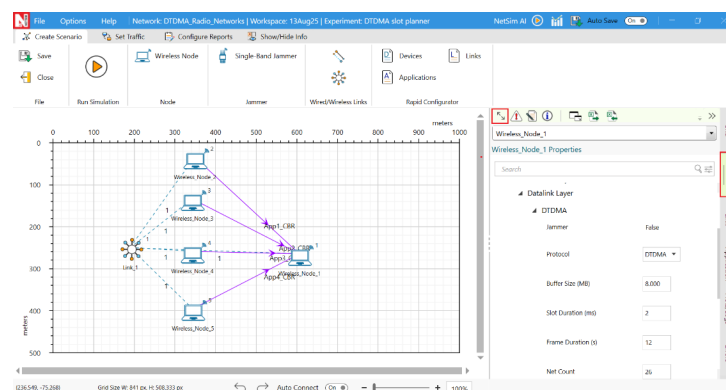


**Figure 4-3:** Datalink layer properties window for wireless node

- Set the slot allocation technique to File based and click on the via GUI option in Configure Slot Planner to get the DTDMA Slot Planner window

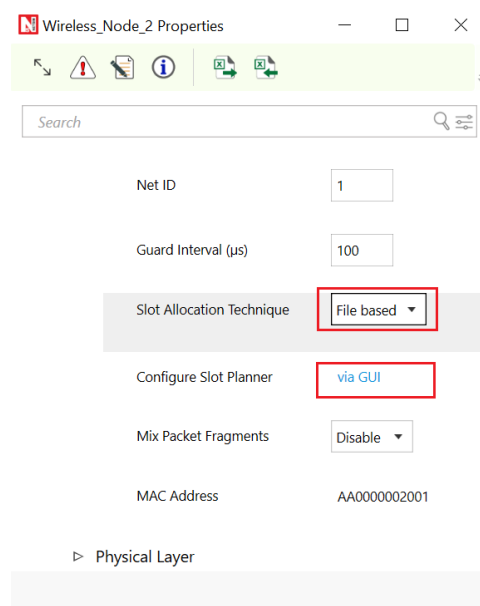


**Figure 4-4:** Slot Allocation Technique Datalink layer properties window

- Click on the Configure Slot Planner link to get the DTDMA Slot Planner window.

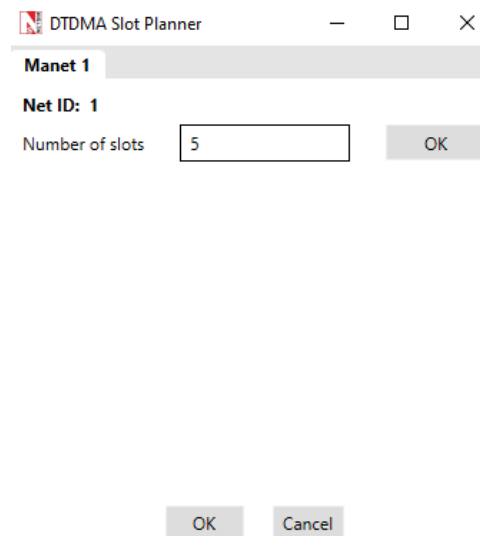


**Figure 4-5:** DTDMA Slot Planner window.

- To set the slot allocation pattern, enter the Number of slots in the text box and click on OK.

**DTDMA Slot Planner**

**Manet 1**

**Net ID: 1**

Number of slots:

| Device Name     | Slot 1                | Slot 2                | Slot 3                | Slot 4                | Slot 5                |
|-----------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| Wireless_Node_1 | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Wireless_Node_2 | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Wireless_Node_3 | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Wireless_Node_4 | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Wireless_Node_5 | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |

**Figure 4-6:** Number of slots in DTDMA Slot Planner window

- If you prefer to allocate slots to all devices in the network, you will have to enter the number of slots equivalent or greater than the number of devices in your network scenario. The pattern defined by the user will be repeated throughout the simulation.
- Use the radio buttons to allocate a specific slot to a particular device matching the row which contains the device name and column which contains the slot id.

**DTDMA Slot Planner**

**Manet 1**

**Net ID: 1**

Number of slots:

| Device Name     | Slot 1                           | Slot 2                           | Slot 3                           | Slot 4                           | Slot 5                           |
|-----------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| Wireless_Node_1 | <input checked="" type="radio"/> | <input type="radio"/>            | <input type="radio"/>            | <input type="radio"/>            | <input type="radio"/>            |
| Wireless_Node_2 | <input type="radio"/>            | <input type="radio"/>            | <input type="radio"/>            | <input checked="" type="radio"/> | <input type="radio"/>            |
| Wireless_Node_3 | <input type="radio"/>            | <input checked="" type="radio"/> | <input type="radio"/>            | <input type="radio"/>            | <input type="radio"/>            |
| Wireless_Node_4 | <input type="radio"/>            | <input type="radio"/>            | <input checked="" type="radio"/> | <input type="radio"/>            | <input type="radio"/>            |
| Wireless_Node_5 | <input type="radio"/>            | <input type="radio"/>            | <input type="radio"/>            | <input type="radio"/>            | <input checked="" type="radio"/> |

**Figure 4-7:** Allocate a specific slot to a particular device

- Here the slots are allocated in the order, Wireless Node 1, 3, 4, 2 and 5.
- Click on OK button to apply the configured pattern.
- In PHY LAYER properties, Bandwidth is set to 100kHz, Data symbol rate is set to 100kBd, and Code Rate is set to 5/6.
- The routing protocol in the network layer is set to DSR for all nodes. As this is a global property, changing it on one node will affect all nodes.
- Create 4 CBR Application with default settings from Wireless Node 2, 3, 4, 5 to 1 by clicking on the set traffic tab from ribbon on the top.

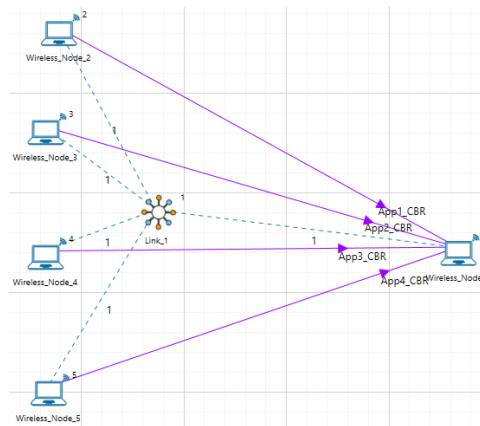


**Figure 4-8:** *Network Topology*

- Enable the packet trace and DTDMA slot allocation log from plots/logs option on right panel and run the simulation for 100sec.

## Results

- After the simulation, open the DTDMA slot allocation log from the simulation results window.

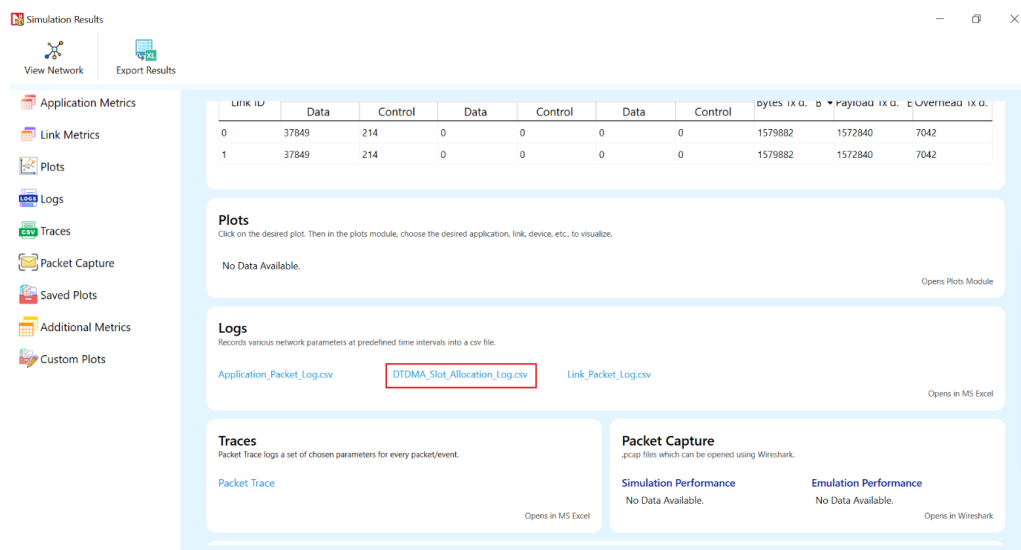
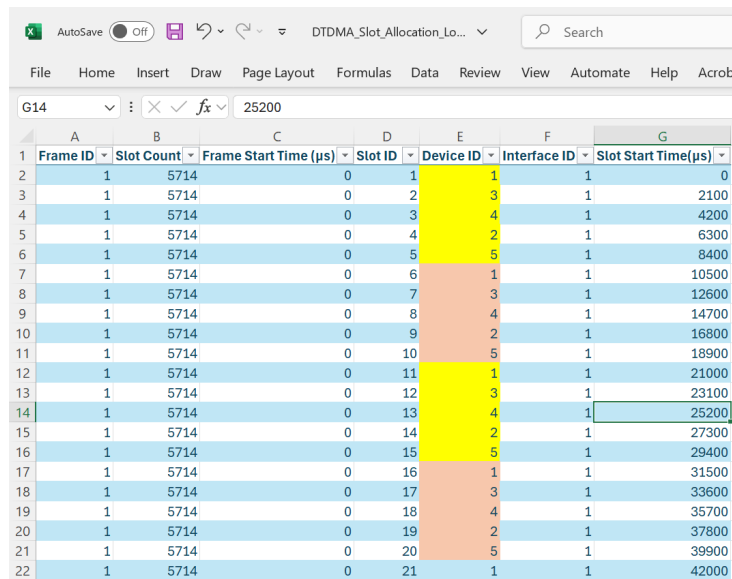


**Figure 4-9:** *Open DTDMA Slot allocation log from simulation results window*

- In the DTDMA slot allocation log check the Device Id column you will be able to observe the slot allocation pattern as per the configuration done in GUI. Wireless Node 1, 3, 4, 2 and 5.



|    | A        | B          | C                     | D       | E         | F            | G                   |
|----|----------|------------|-----------------------|---------|-----------|--------------|---------------------|
|    | Frame ID | Slot Count | Frame Start Time (μs) | Slot ID | Device ID | Interface ID | Slot Start Time(μs) |
| 1  | 1        | 5714       | 0                     | 1       | 1         | 1            | 0                   |
| 2  | 1        | 5714       | 0                     | 2       | 3         | 1            | 2100                |
| 3  | 1        | 5714       | 0                     | 3       | 4         | 1            | 4200                |
| 4  | 1        | 5714       | 0                     | 4       | 2         | 1            | 6300                |
| 5  | 1        | 5714       | 0                     | 5       | 5         | 1            | 8400                |
| 6  | 1        | 5714       | 0                     | 6       | 1         | 1            | 10500               |
| 7  | 1        | 5714       | 0                     | 7       | 3         | 1            | 12600               |
| 8  | 1        | 5714       | 0                     | 8       | 4         | 1            | 14700               |
| 9  | 1        | 5714       | 0                     | 9       | 2         | 1            | 16800               |
| 10 | 1        | 5714       | 0                     | 10      | 5         | 1            | 18900               |
| 11 | 1        | 5714       | 0                     | 11      | 1         | 1            | 21000               |
| 12 | 1        | 5714       | 0                     | 12      | 3         | 1            | 23100               |
| 13 | 1        | 5714       | 0                     | 13      | 4         | 1            | 25200               |
| 14 | 1        | 5714       | 0                     | 14      | 2         | 1            | 27300               |
| 15 | 1        | 5714       | 0                     | 15      | 5         | 1            | 29400               |
| 16 | 1        | 5714       | 0                     | 16      | 1         | 1            | 31500               |
| 17 | 1        | 5714       | 0                     | 17      | 3         | 1            | 33600               |
| 18 | 1        | 5714       | 0                     | 18      | 4         | 1            | 35700               |
| 19 | 1        | 5714       | 0                     | 19      | 2         | 1            | 37800               |
| 20 | 1        | 5714       | 0                     | 20      | 5         | 1            | 39900               |
| 21 | 1        | 5714       | 0                     | 21      | 1         | 1            | 42000               |

**Figure 4-10:** Slot allocation pattern in DTDMA slot allocation log.

**DTDMA Slot Planner for Multiple MANETs** In the similar way slot allocation pattern can be defined for Multiple MANETs also. Here you will have multiple tables in the slot planner, corresponding to each MANET. Note that slot allocation for multiple MANETs can be configured by accessing Interconnected TDMA Radio Network module.

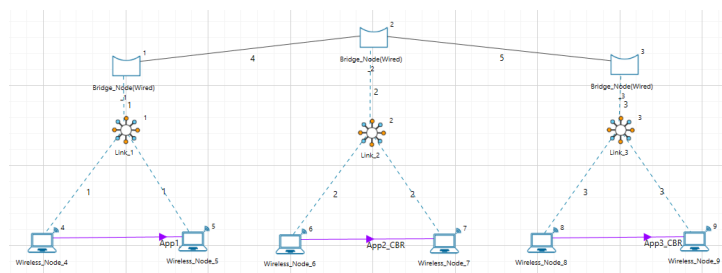


**Figure 4-11:** Network Topology

**Manet 1**

Net ID: 1

Number of slots: 4

| Device Name      | Slot 1                | Slot 2                | Slot 3                | Slot 4                |
|------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| Bridge_Node(Wire | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Wireless_Node_4  | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Wireless_Node_5  | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |

**Manet 2**

Net ID: 2

Number of slots: 4

| Device Name      | Slot 1                | Slot 2                | Slot 3                | Slot 4                |
|------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| Bridge_Node(Wire | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Wireless_Node_6  | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Wireless_Node_7  | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |

**Manet 3**

Net ID: 3

Number of slots: 4

| Device Name      | Slot 1                | Slot 2                | Slot 3                | Slot 4                |
|------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| Bridge_Node(Wire | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Wireless_Node_8  | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Wireless_Node_9  | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |

**Figure 4-12:** DTDMA Slot Planner for Multiple MANETs

The Net ID parameter in the Data link layer properties should be set for all the nodes based on the MANET network to which it belongs.

For example: All nodes belonging to MANET 3 should have the Net ID set to 3.

Wireless\_Node\_2 Properties

Search

**Datalink Layer**

**DTDMA**

Protocol: DTDMA

Slot Duration (ms): 2

Frame Duration (s): 12

Net Count: 26

Net ID: 3

**Figure 4-13:** Net ID in Datalink layer properties

#### 4.1.2 Packet size and Slot Allocation Analysis

Open NetSim, Select **Examples**▷**TDMA Radio Networks** ▷**DTDMA**▷**Packet Size and Slot Allocation** then click on the tile in the middle panel to load the example as shown in the screenshot below.

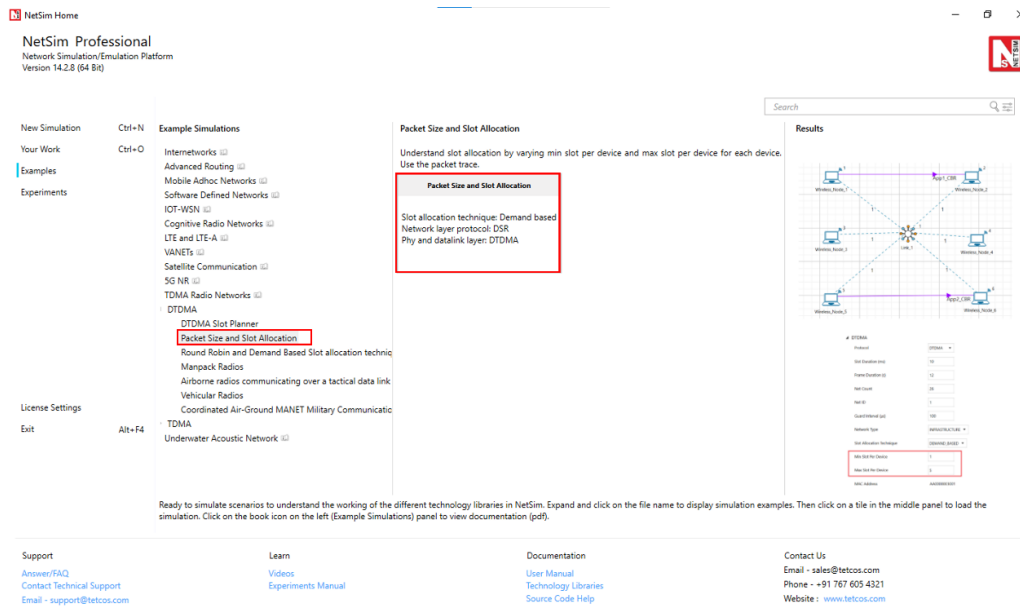


**Figure 4-14:** *List of scenarios for the example of Packet Size and Slot Allocation*

The following network diagram illustrates what the NetSim UI displays when you open the example configuration file `Packet-Size-and-Slot-Allocation` as shown below.

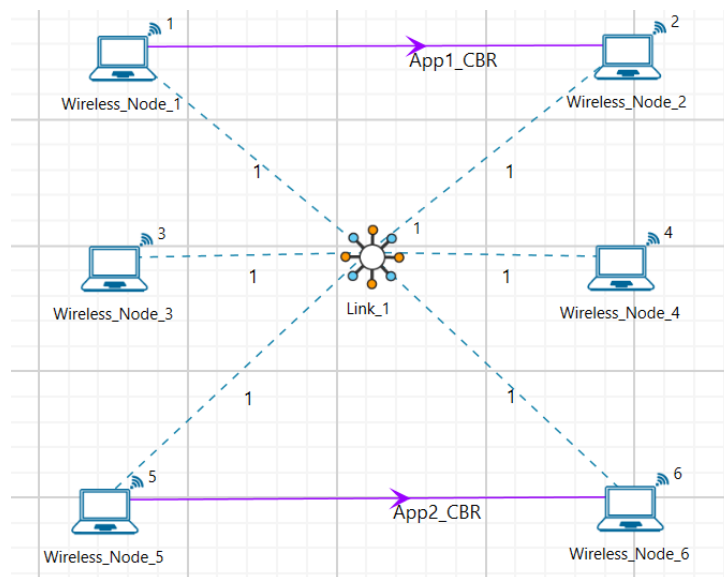


**Figure 4-15:** *Network set up for studying the Packet Size and Slot Allocation*

The following are the main properties of DTDMA in Phy and Datalink layers.

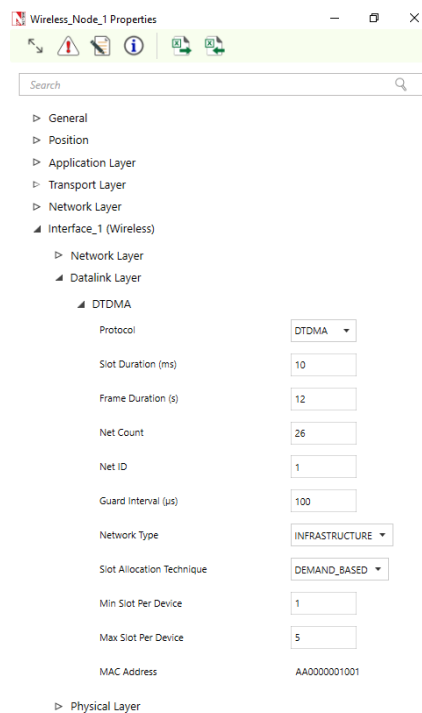


**Figure 4-16:** DTDMA Protocol in Datalink layer properties

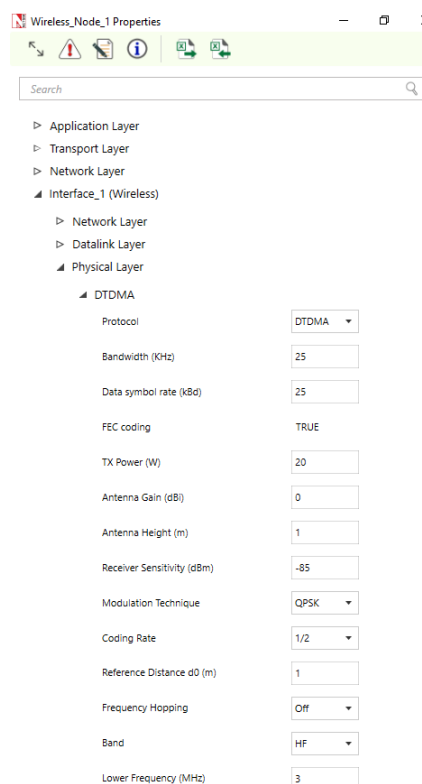


**Figure 4-17:** DTDMA Protocol in Physical layer properties

Settings done in example config file:

In DTDMA, time is divided into slots. In between 2 slots there is a guard interval of  $100\mu s$ .

1. Set grid length to  $1000m * 500m$  from grid setting property panel on the right. This needs to be done before any device is placed on the grid.

2. In the wireless nodes DTDMA protocol is set in Interface\_1 (Wireless) datalink layer. To configure any properties in the nodes, click on the node, expand the property panel on the right side, and change the properties as mentioned in the below steps.

**Table 4-1:** *Device properties set in wireless nodes*

| Device Properties                      |              |
|----------------------------------------|--------------|
| <b>Network layer properties</b>        |              |
| Routing protocol                       | DSR          |
| <b>Interface (Wireless) properties</b> |              |
| <b>Datalink layer properties</b>       |              |
| Slot Duration                          | 10 ms        |
| Guard interval                         | 100 $\mu$ s. |
| Slot allocation technique              | Demand based |
| Minimum slots per device               | 1            |
| Maximum slots per device               | 5            |
| <b>Physical layer properties</b>       |              |
| Bandwidth                              | 25 KHz       |
| Data symbol Rate                       | 25 kBd       |

3. Configure CBR application from Wireless node 1 to 2 by clicking on set traffic tab on ribbon in the top. Click on the created application, in the property panel on the right, set the Packet Size = 1000 B, IAT = 20000  $\mu$ s and transport protocol as UDP.
4. Enable Packet trace from configure reports tab in ribbon on top.
5. Run simulation for 100 seconds.

**Results:** Users can observe how the slots are allocated for each device in detail in Packet trace. In this case, packet size is 1000 B or 8000 bits. One slot is allocated for each device and the slot size is 333 bits. Since one packet of 8000 bits won't fit in a slot fragmentation is done in the Phy layer.

Users can observe this in Packet trace by filtering the CONTROL PACKET TYPE/APP\_NAME to APP1 CBR. Packets of any greater size are fragmented. Fragmentation also takes into account the number of bits remaining in the allocated slot to improve slot utilization.

For a slot size of 250 bits, 1036 B packets will be fragmented as

Slot 1 - 31.25 bytes  
 Slot 2 - 31.25 bytes  
 Slot 3 - 31.25 bytes  
 Slot 4 - 31.25 bytes  
 Slot 5 - 31.25 bytes ... and so on till the 33rd slot  
 Slot 34 - 4.75 bytes  
 Slot 35 - 26.5 bytes  
 Slot 36 - 31.25 bytes

... and so on

In packet trace, filter column of PACKET TYPE to CBR. Select source ID as Node-1 and see the results in PHY LAYER PAYLOAD (Bytes)

**Figure 4-18:** *Packet Trace*

**Figure 4-19:** *Packet Trace*

### 4.1.3 Round Robin and Demand Based slot allocation techniques

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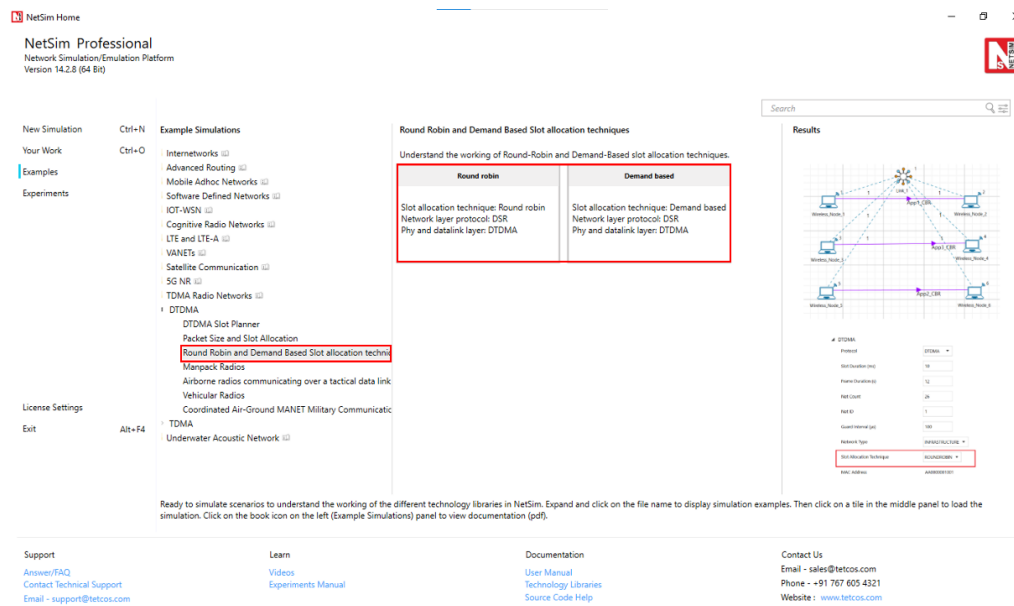


**Figure 4-20:** List of scenarios for the example of Round Robin and Demand Based Slot allocation techniques

The following network diagram illustrates what the NetSim UI displays when you open the example configuration file Round-Robin-and-Demand-Based-Slot-allocation-techniques as shown below.

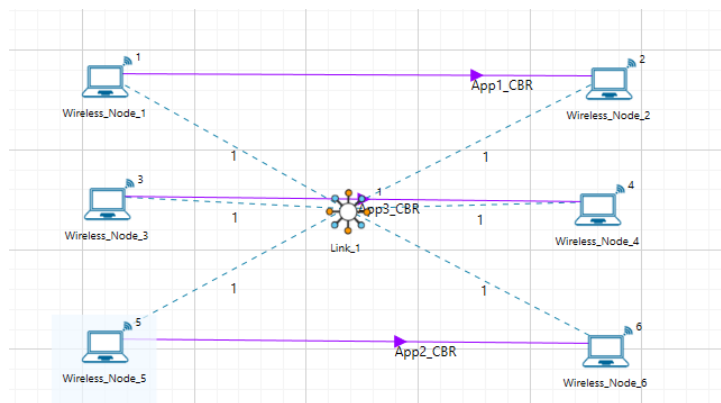


**Figure 4-21:** Network set up for studying the Round Robin and Demand Based Slot allocation techniques.

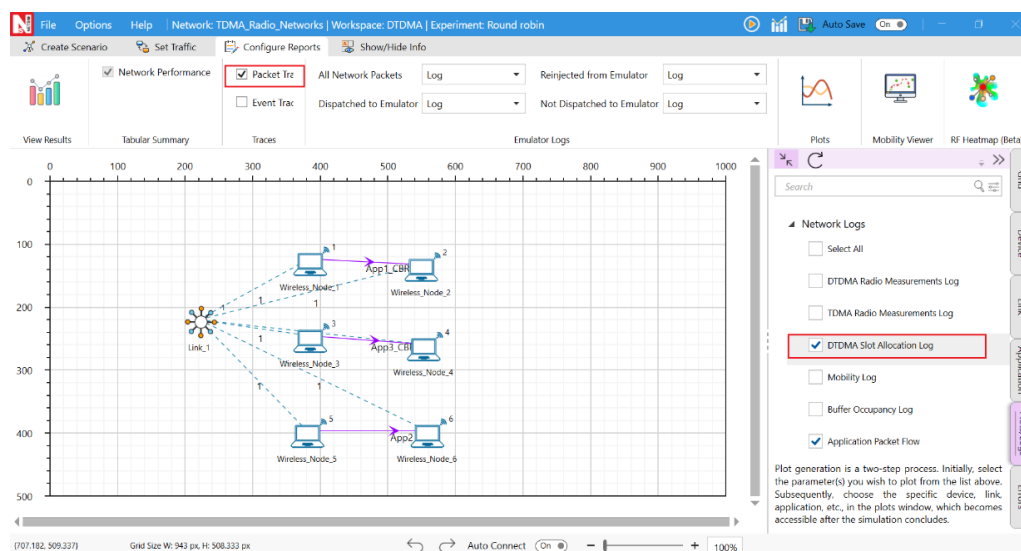
**Round Robin** Settings done in example config file:

1. Set grid length as 1000m \* 500m from grid setting property panel on the right. This needs to be done before any device is placed on the grid.
2. In the wireless nodes DTDMA protocol is set in Interface 1 (Wireless) datalink layer. To configure any properties in the nodes, click on the node, expand the property panel on the right side, and change the properties as mentioned in the below steps.

**Table 4-2:** Device properties set in wireless nodes

| Device Properties                      |              |
|----------------------------------------|--------------|
| <b>Network layer properties</b>        |              |
| Routing protocol                       | DSR          |
| <b>Interface (Wireless) properties</b> |              |
| <b>Datalink layer properties</b>       |              |
| Slot Duration                          | 10 ms        |
| Guard interval                         | 100 $\mu$ s. |
| Slot allocation technique              | Round robin  |
| <b>Physical layer properties</b>       |              |
| Bandwidth                              | 25 KHz       |
| Data symbol Rate                       | 25 kBd       |

- Configure CBR application as shown in scenario by clicking on set traffic tab on ribbon in the top. Click on the created application, in the property panel on the right, set the Packet Size = 1000 B, IAT = 20000  $\mu$ s, start time as 5 sec and transport protocol as UDP.
- Enable DTDMA slot allocation log and Packet trace from configure reports tab in ribbon on top as shown below.

**Figure 4-22:** Enabling of Packet trace and DTDMA Slot Allocation log

- Run simulation for 100 seconds.
- NOTE:** The PHY layer properties should be changed manually in all Nodes.

**Results** DTDMA slot allocation log results: Open DTDMA slot allocation log file, ROUND ROBIN allocates slots to each device present in the network regardless of whether the nodes are generating traffic or not as shown below.

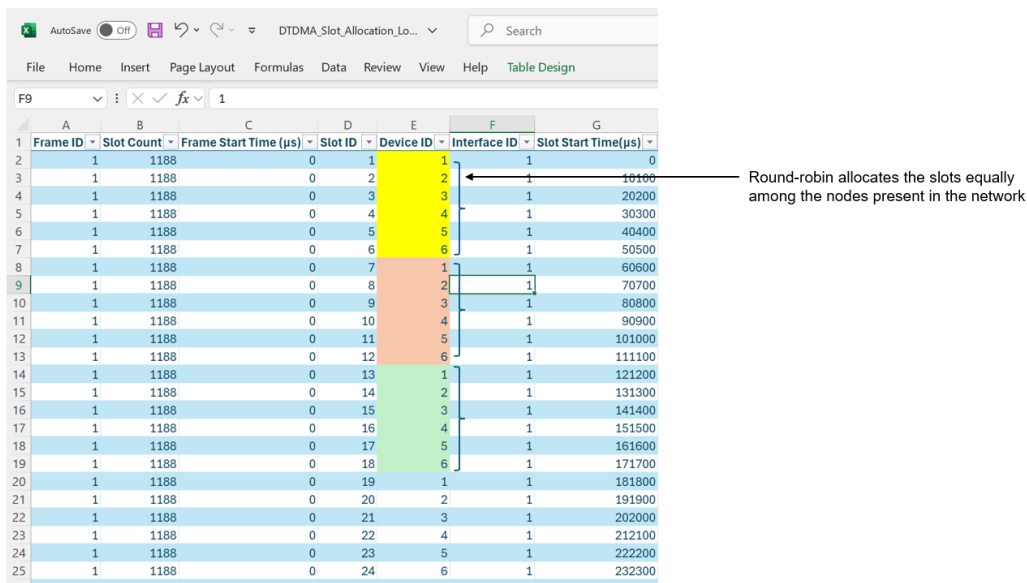


**Figure 4-23:** Round robin slot allocation shown in DTDMA slot allocation log file

### Packet trace results

Open packet trace from simulation results window and filter PACKET TYPE to CBR. The slot duration is  $10\text{ms} = 10000\mu\text{s}$ . In between 2 slots there is a guard interval of  $100\mu\text{s}$ . In this scenario Nodes 5, 1 and 3 are generating traffic and users can see that the PHY LAYER END time difference between TX-ID Node-5 and TX-ID Node-1 is  $5262000\mu\text{s} - 5282200\mu\text{s} = 20200\mu\text{s} = 2\text{ slots}$  (including guard interval). This implies slot-1 is assigned to Node-5 and slot-2 is assigned to Node-6. Time difference between TX-ID Node-1 and TX-ID Node-3 is  $5282201\mu\text{s} - 5302400\mu\text{s} = 20200\mu\text{s} = 2\text{ slots}$  (including guard interval). This implies slot-3 is assigned to Node-1 and slot-4 is assigned to Node-2. Similarly, slot-5 is assigned to Node-3 and slot-6 is assigned to Node-4. The slots are equally assigned to all the six nodes.

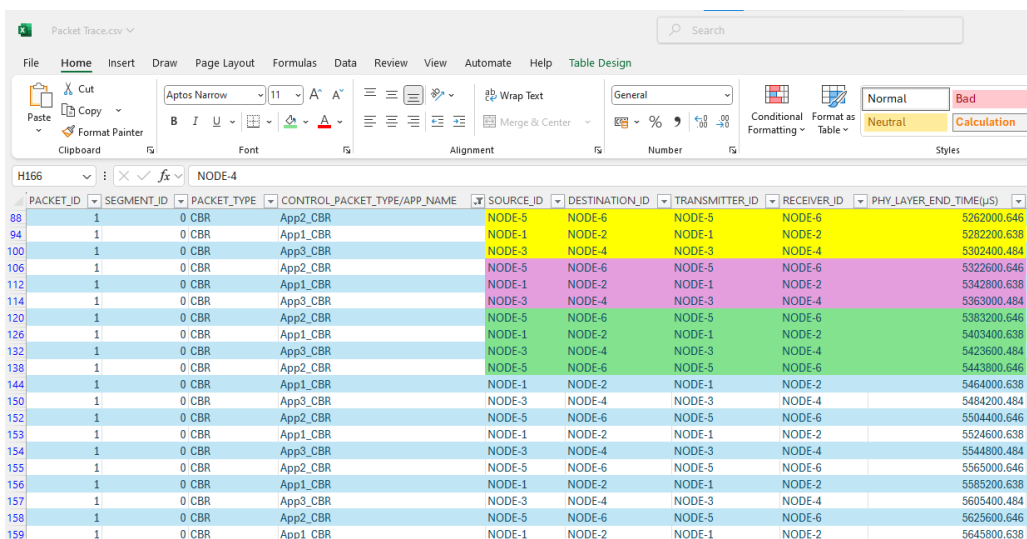


**Figure 4-24:** Slot allocation and data transmission shown in Packet Trace

The tables below show which packet is transmitted in each slot by cross-referencing the packet trace with the slot allocation log.

### First cycle

**Table 4-3:** Slots Allocation time for First cycle

| Node ID                                | Node-5   | Node-6  | Node-1   | Node-2  | Node-3   | Node-4  |
|----------------------------------------|----------|---------|----------|---------|----------|---------|
| Control Packet Type / Application Name | APP2 CBR | N/A     | APP1 CBR | N/A     | APP3 CBR | N/A     |
| PHY LAYER ENDTIME ( $\mu$ s)           | 5262000  | 5272100 | 5282200  | 5292300 | 5302400  | 5312500 |

Second cycle

**Table 4-4:** Slots allocation time for second cycle

| Node ID                                | Node-5   | Node-6  | Node-1   | Node-2  | Node-3   | Node-4  |
|----------------------------------------|----------|---------|----------|---------|----------|---------|
| Control Packet Type / Application Name | APP2 CBR | N/A     | APP1 CBR | N/A     | APP3 CBR | N/A     |
| PHY LAYER END TIME ( $\mu$ s)          | 5322600  | 5332700 | 5342800  | 5352900 | 5363000  | 5373100 |

NetSim will execute multiple such iterations similar to first and second iteration for slot allocation. Users can compare the above table with the packet trace by filtering Packet Type to CBR.

**Demand Based** Settings done in example config file:

1. The setting is similar to the above round robin case. Change the following properties in wireless node Interface (Wireless) layer of datalink layer.

**Table 4-5:** Device properties set in wireless nodes

| Device Properties                      |              |
|----------------------------------------|--------------|
| <b>Network layer properties</b>        |              |
| Routing protocol                       | DSR          |
| <b>Interface (Wireless) properties</b> |              |
| <b>Datalink layer properties</b>       |              |
| Slot Duration                          | 10 ms        |
| Guard interval                         | 100 $\mu$ s. |
| Slot allocation technique              | Demand based |
| Minimum slots per device               | 1            |
| Maximum slots per device               | 5            |
| <b>Physical layer properties</b>       |              |
| Bandwidth                              | 25 KHz       |
| Data symbol Rate                       | 25 kBd       |

2. Run Simulation for 100 seconds.
3. **NOTE:** The PHY layer properties should be changed manually in all Nodes.

**Results** DTDMA slot allocation log:

In demand-based slot allocation, slots are allocated to devices according to the minimum and maximum slot counts set per device.

Open the DTDMA slot allocation log file and filter the slot count to 18. The slot count is 18 because it is calculated as follows:

(Maximum slots per device  $\times$  number of transmitting nodes) + (Minimum slots per device  $\times$  number of non-transmitting nodes),  $(5 \times 3) + (1 \times 3) = 18$ .

In this case, the maximum slots allocated per device are 5, and the minimum slots allocated per device are 1. The maximum number of slots is allotted to nodes with traffic, while the minimum slots are allotted to non-transmitting nodes. From the figure below, we can observe the Max Slots per Device and Min Slots per Device allocated for device

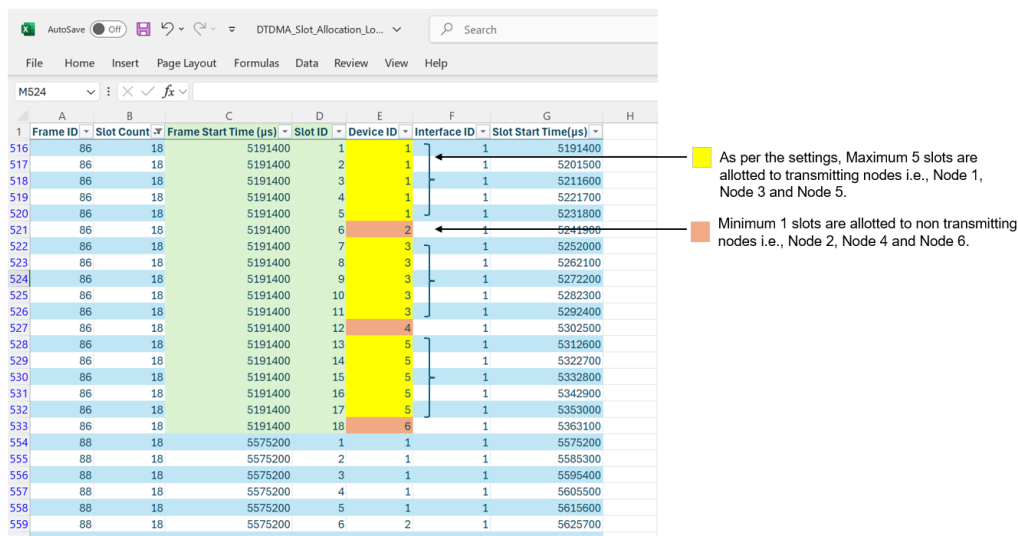


**Figure 4-25:** Demand based slot allocation shown in DTDMA slot allocation log file

The above is shown for first frame where the slots are allocated and subsequently, the next frame starts at 5575200  $\mu$ s, and the next 18 slots will be allocated according to the maximum and minimum slot settings.

Packet trace results:

Open the packet trace from the simulation results window and filter PACKET TYPE to CBR. The slot duration is set to 10 ms (10,000  $\mu$ s), and the guard interval is set to 100  $\mu$ s, resulting in slots being assigned every 10,100  $\mu$ s. In this scenario, Nodes 5, 1, and 3 are generating traffic. Users can observe that slot assignments and data transmission occur according to the maximum and minimum slot settings. Initially, due to packet queuing, slots might not be allocated as per the settings. Eventually, a maximum of 5 slots is assigned to Node 5, followed by 5 slots each for Nodes 1 and 3. Observe this in packet trace screenshot below.

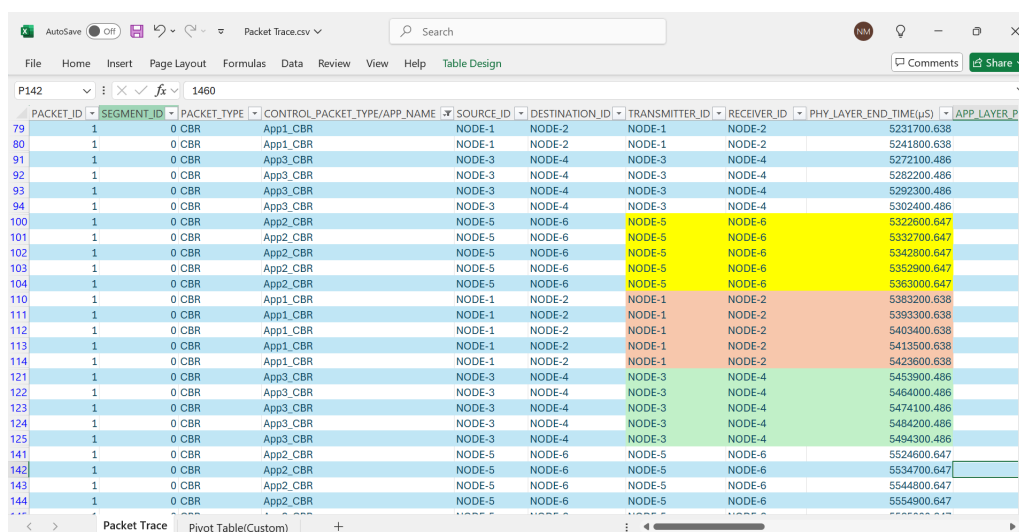


**Figure 4-26:** Slot allocation and data transmission shown in Packet Trace

The table below shows which packet is transmitted in each slot by cross-referencing the packet trace with the slot allocation log.

**Table 4-6:** Slot allocation technique for Node-5

| Node-5                                 |          |          |          |          |          |
|----------------------------------------|----------|----------|----------|----------|----------|
| Slot ID                                | 1        | 2        | 3        | 4        | 5        |
| Packet ID                              | 1        | 1        | 1        | 1        | 1        |
| Control Packet Type / Application Name | APP2 CBR | APP2 CBR | APP2 CBR | APP2 CBR | APP2 CBR |
| PHY LAYER END TIME ( $\mu$ s)          | 5322600  | 5332700  | 5342800  | 5352900  | 5363000  |

Similar slot allocation is also done for the other nodes. Compare the above table with packet trace by filtering Packet Type to CBR.

#### 4.1.4 Network of airborne radios and ground station connected over a tactical data link

Scenario and objective: A Ground Station (GS) is connected to the Early Warning Radar (EWR), via ground network infrastructure and is connected to friendly aircraft over a TDMA based data link. The GS starts up the network, does the time slot assignment, generates the crypto key and the frequency hopping pattern. The GS then periodically broadcasts the Recognized Air Picture (RAP) to all friendly aircraft, while all the friendly aircraft periodically broadcast their positions to one another and to the GS. The RAP is a complete listing of all aircraft (friendly and hostile) within the airspace; this RAP application has a larger packet size and with a higher traffic rate as compared to the position reports (PRs) which have a small packet size and a low traffic rate. Latency is an important consideration. Both the PRs and the RAP must reach their intended destinations with the lowest possible delay. The questions we ask are: (i) given a constant traffic rate, is it better to send larger RAP packets less frequently or should we transmit smaller RAP packets more often? and (ii) which slot allocation technique is more efficient.

- Open NetSim and Select **Examples** > **TDMA Radio Networks** > **DTDMA** > **Airborne radios communicating over a tactical data link** then click on the tile in the middle panel to load the example.

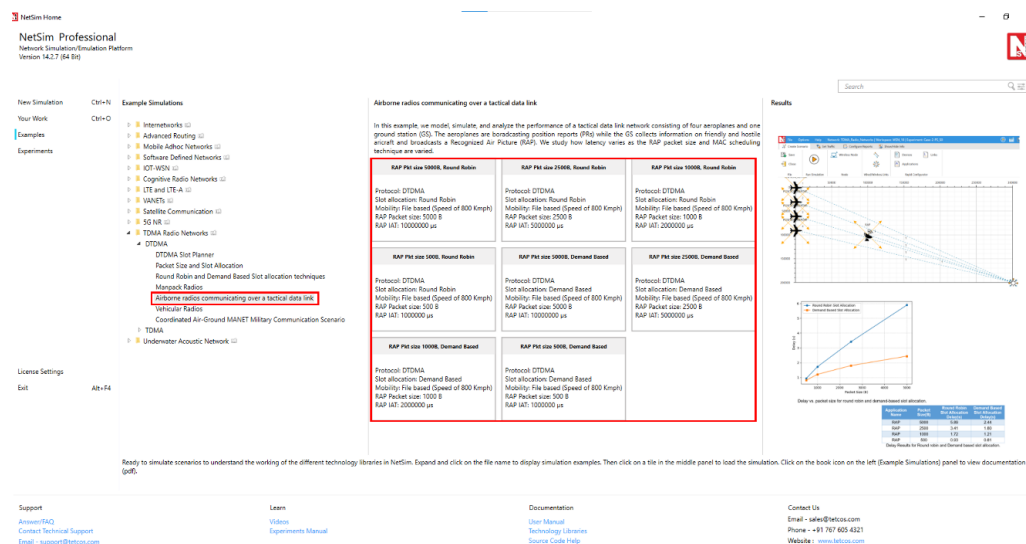


**Figure 4-27:** List of scenarios for the example of Airborne radios communicating over a tactical data link.

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

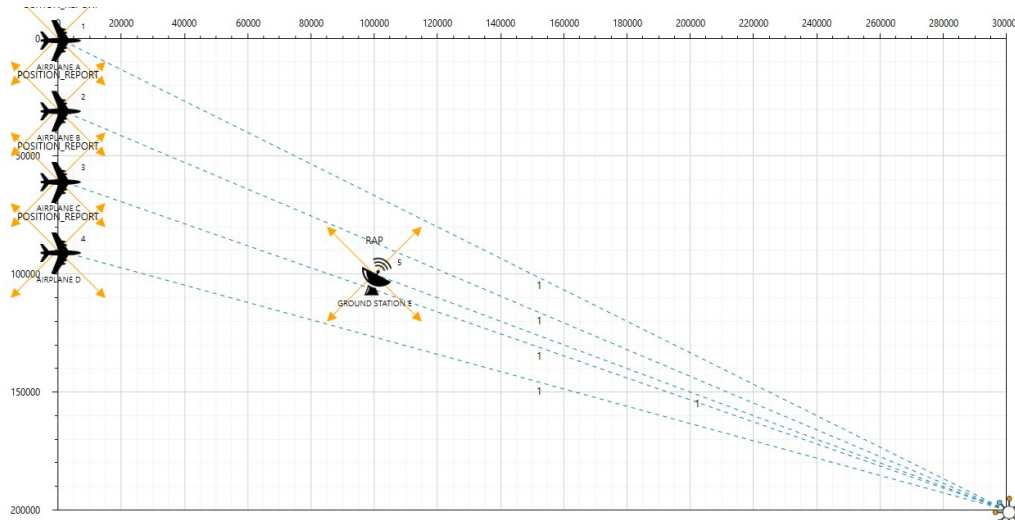


**Figure 4-28:** Network set up for studying the 4 POSITIONS REPORT and 1 RAP.

Settings done in the network:

**Table 4-7:** Device settings in different layers

| Parameter                 | Values                                         |
|---------------------------|------------------------------------------------|
| Grid Size                 | 300 × 150 Km                                   |
| <b>RF Propagation</b>     |                                                |
| Channel Characteristics   | Pathloss                                       |
| Pathloss model            | Range based                                    |
| Range(m)                  | 100000                                         |
| <b>Data Link Layer</b>    |                                                |
| Protocol                  | DTDMA                                          |
| Slot Duration             | 50ms                                           |
| Guard Interval            | 2000 $\mu$ s                                   |
| Slot Allocation Technique | Round Robin, Demand Based                      |
| <b>Physical Layer</b>     |                                                |
| Bandwidth                 | 25 KHz                                         |
| Data Symbol Rate          | 25 kBd                                         |
| Transmitter Power         | 20W                                            |
| Modulation Technique      | QPSK                                           |
| RX sensitivity            | -108dBm                                        |
| Band                      | UHF                                            |
| Lower Frequency           | 300MHz                                         |
| Upper Frequency           | 512MHz                                         |
| <b>Mobility</b>           |                                                |
| File based mobility       | Nodes move West to east at a speed of 800 Kmph |

**NOTE:** The PHY layer properties should be changed manually in all Nodes.

Application Properties: Set Transport Protocol to UDP.

**Table 4-8:** *Application Properties.*

| <b>Application Method – Broadcast, Application type – CBR, Encryption – AES, Transport Protocol - UDP</b> |                       |                  |                            |                                              |
|-----------------------------------------------------------------------------------------------------------|-----------------------|------------------|----------------------------|----------------------------------------------|
| <b>Application Name</b>                                                                                   | <b>Application Id</b> | <b>Source Id</b> | <b>Packet size (Bytes)</b> | <b>Interarrival time (<math>\mu</math>s)</b> |
| POSITION REPORT I                                                                                         | 1                     | 1                | 50                         | 2000000                                      |
| POSITION REPORT II                                                                                        | 2                     | 2                | 50                         | 2000000                                      |
| POSITION REPORT III                                                                                       | 3                     | 3                | 50                         | 2000000                                      |
| POSITION REPORT IV                                                                                        | 4                     | 4                | 50                         | 2000000                                      |
| RAP                                                                                                       | 5                     | 5                | 5000                       | 10000000                                     |

We observe the latency of the RAP application for different packet sizes and for different slot allocation techniques. The total generation rate is kept constant while the packet size of the RAP application is varied. The question we ask is: Is it better to send larger RAP packets less frequently or should we transmit smaller RAP packets more often? The eight cases with the generation rates, inter packet arrival times, packet sizes and scheduling algorithm are given in the table below.

**Table 4-9:** *Application settings for different scheduling techniques.*

| <b>Case #</b> | <b>Scheduling technique</b>  | <b>RAP Packet size (Bytes)</b> | <b>RAP IAT (<math>\mu</math>s)</b> | <b>RAP Gen. Rate (Kbps)</b> |
|---------------|------------------------------|--------------------------------|------------------------------------|-----------------------------|
| 1             | Round Robin Slot allocation  | 5000                           | 10000000                           | 4                           |
| 2             | Round Robin Slot allocation  | 2500                           | 5000000                            | 4                           |
| 3             | Round Robin Slot allocation  | 1000                           | 2000000                            | 4                           |
| 4             | Round Robin Slot allocation  | 500                            | 1000000                            | 4                           |
| 5             | Demand Based Slot allocation | 5000                           | 10000000                           | 4                           |
| 6             | Demand Based Slot allocation | 2500                           | 5000000                            | 4                           |
| 7             | Demand Based Slot allocation | 1000                           | 2000000                            | 4                           |
| 8             | Demand Based Slot allocation | 500                            | 1000000                            | 4                           |

Two scheduling algorithms, round robin and demand-based slot allocation are run. Enable plots and Run Simulation for 1350 seconds, during which the airplanes cover a 300 kms distance.

**Configuring Mobility Paths for Airplanes** Airplane mobility can be viewed in NetSim using the Mobility Viewer option available in the Configure Report tab, which can be observed prior to simulation. Since we have defined file-based mobility, the paths can be observed before the simulation. Follow the procedure below to view the mobility

Click on Configure Report tab > select Mobility viewer > choose display properties as shown below

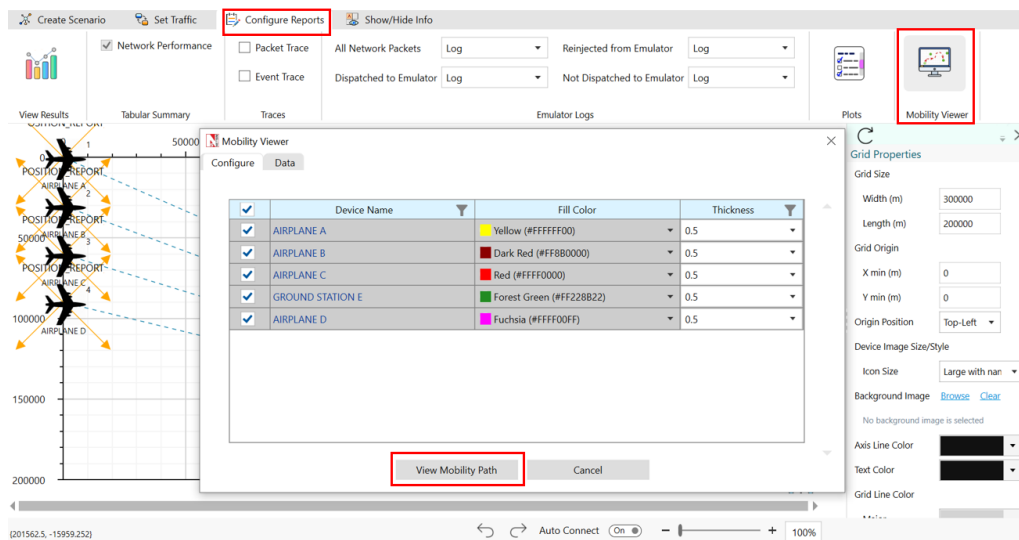


**Figure 4-29:** Enabling the Mobility Viewer option in Configure Reports tab

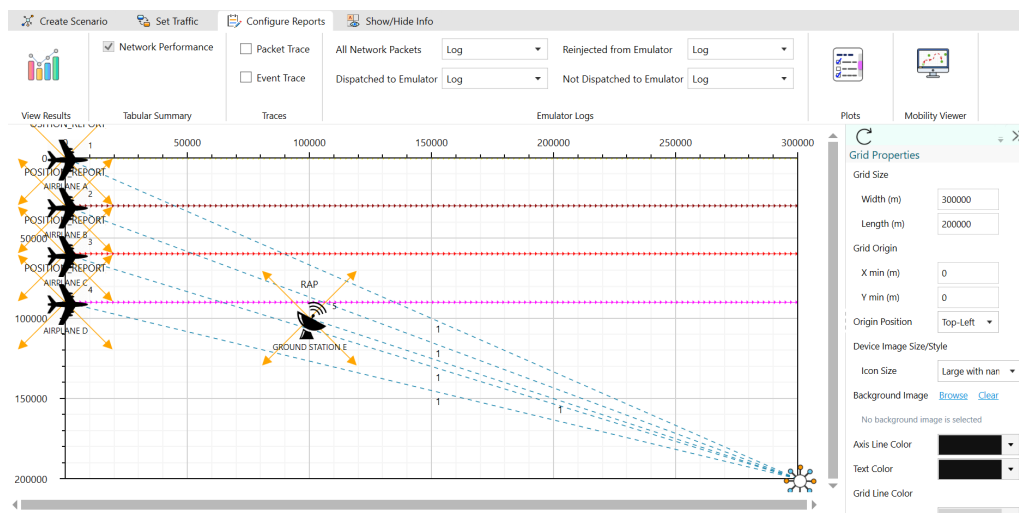


**Figure 4-30:** Mobility path for Airplanes

**Table 4-10:** Delay Results for Round robin and Demand based slot allocation, for different packet sizes

| Application Name | Packet Size(B) | Round Robin Aggregated Delay(s) | Demand Based Aggregated Delay(s) |
|------------------|----------------|---------------------------------|----------------------------------|
| RAP              | 5000           | 6.02                            | 2.42                             |
| RAP              | 2500           | 3.42                            | 1.63                             |
| RAP              | 1000           | 1.72                            | 1.21                             |
| RAP              | 500            | 0.93                            | 0.81                             |

## Results

- We observe that in both Round Robin and Demand based slot allocation, the end-to-end latency of RAP application increases with packet size. The smallest packet size of 500B gives the lowest latencies. The reason is that larger RAP packets get fragmented, for example, a 5000B packet gets fragmented into 4 segments (of size 1480B, 1480B, 1480B and 560B) since the maximum packet size that can be sent in a slot is 1480B. At the destination the network layer needs to wait for all segments to arrive and only then assemble them back into a packet and transmit it up to the application layer.

- Next, we observe that demand-based slot allocation performs better than round robin slot allocation in terms of latency. In our scenario the RAP application requires more resources (slots) than the position reports. In case of round robin, slots are allocated in a round robin fashion to airplanes and to the GS. In the case of demand-based slot allocation the allocation of slots is carried out on the basis of application demand (load). Since the RAP application has a higher rate, more slots are allocated to the GS as compared to the airplanes. This leads to a better performance. The tradeoff is complexity; round robin scheduling is simple to implement unlike demand-based scheduling.

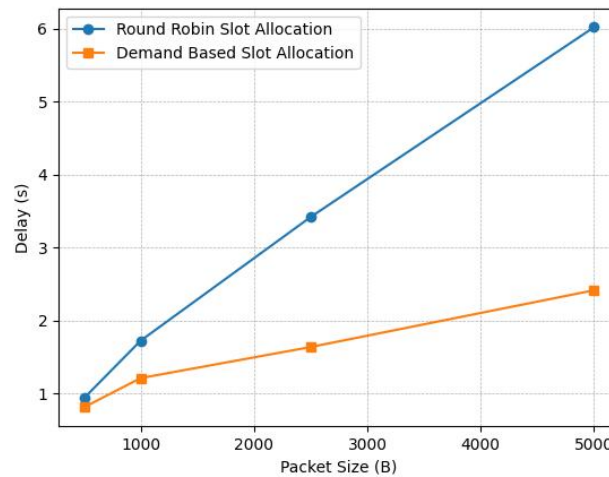


**Figure 4-31:** Delay vs. packet size for round robin and demand-based slot allocation. Firstly, we see that a lower packet size (while keeping the generation rate constant) leads to a lower delay. Secondly, it is evident that demand-based slot allocation leads to a lower latency than round robin slot allocation.

#### 4.1.5 Manpack Radios

Objective: Model and simulate a Tactical MANET radio network and compare the performance of AODV and OLSR routing protocols. The MANET network comprises 28 soldier nodes carrying manpack radios. They are logically grouped into four teams and follow a group mobility model.

Application traffic is configured using randomized source-destination pairs among the 28 nodes. The number of concurrent applications is increased incrementally from 1 up to 28, to simulate rising traffic demand in a tactical scenario. Performance metrics such as average per-application throughput and delay are measured to see how each protocol responds to higher network load and contention under mobility.

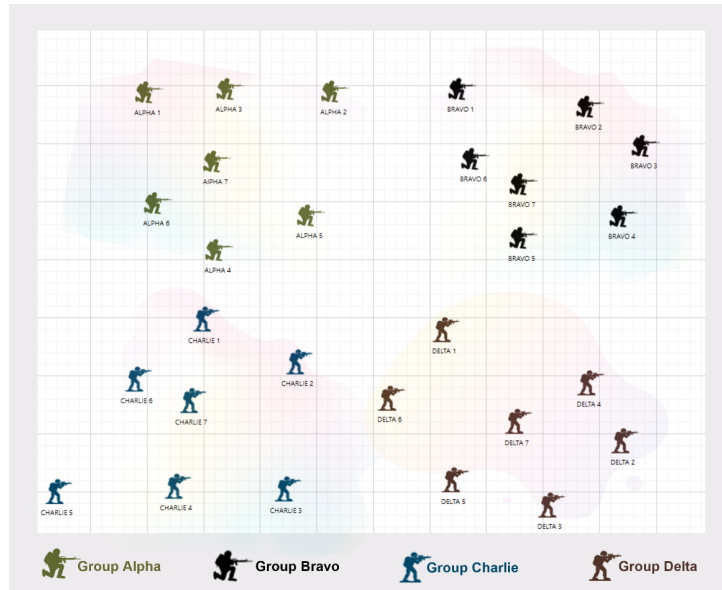


**Figure 4-32:** Network topology showing 28 mobile nodes grouped into Alpha, Bravo, Charlie, and Delta groups. The setup is used to evaluate AODV and OLSR routing protocols under randomized traffic and mobility.

Here Nodes are placed to reflect group-based movement, and directional arrows represent randomized application traffic paths configured for the AODV and OLSR routing protocol. This setup forms the basis for evaluating routing performance under varying traffic loads and mobility conditions.

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

**Table 4-11:** Device properties set in wireless nodes.

| Simulation Parameters                  |                |
|----------------------------------------|----------------|
| Environment size                       | 1750 × 875     |
| Mobility model                         | Group mobility |
| Velocity                               | 5 m/s          |
| Calculation Interval                   | 3 seconds      |
| <b>Interface (Wireless) properties</b> |                |
| <b>Datalink layer</b>                  |                |
| MAC Protocol                           | DTDMA          |
| Slot Duration(ms)                      | 10             |
| Frame Duration(s)                      | 12             |
| Slot allocation Technique              | Round robin    |
| <b>Physical layer properties</b>       |                |
| Data Symbol Rate (kBd)                 | 10000          |
| Transmitter power (W)                  | 4              |
| Modulation Technique                   | 16QAM          |
| Coding rate                            | 3/4            |
| Band                                   | UHF            |
| Lower Frequency (MHz)                  | 300            |
| Upper Frequency (MHz)                  | 320            |

**Application Traffic Configuration** Configure CBR applications as shown in the below table by clicking on set traffic tab from the ribbon on the top.

**Table 4-12:** *Application properties.*

| Parameter          | Value                   |
|--------------------|-------------------------|
| Traffic Type       | Constant Bit Rate (CBR) |
| Transport Protocol | UDP                     |
| Start time         | 5s                      |
| Packet Size        | 20 Bytes                |
| Inter-Arrival Time | 1000000(1s)             |
| Generation Rate    | 160 bps                 |
| Flow Pattern       | Randomized node pairs   |
| Number of Flows    | Varied from 1 to 28     |

- Set the grid length as 1750×875 Interface (Wireless) properties from grid setting panel on the right. This needs to be done before any device is placed on the grid.
- Number of wireless nodes: 28, organized into 4 groups of 7. The mobility model is set to group mobility and other settings are mentioned below.

**Table 4-13:** *Group-wise Assignment of Node IDs for Mobility Configuration.*

| Group Name | Node IDs | Group ID |
|------------|----------|----------|
| Alpha      | 1 to 7   | 1        |
| Bravo      | 8 to 14  | 2        |
| Charlie    | 15 to 21 | 3        |
| Delta      | 22 to 28 | 4        |

- In the wireless nodes set the protocol to DTDMA in Interface\_1 (Wireless) datalink layer. To configure any properties in the nodes, click on the node, expand the property panel on the right side, and change the properties as mentioned in the table above.
- **NOTE:** The PHY layer properties should be changed manually in all Nodes.
- RF Propagation:
- Click on link and open property panel on the right and set the following properties.

**Table 4-14:** *Link properties.*

| Link Properties         |             |
|-------------------------|-------------|
| Channel Characteristics | Pathloss    |
| Path Loss Model         | Range based |
| Range(m)                | 400         |

All simulation parameters remain consistent across both AODV and OLSR configurations, with the routing protocol being the only difference between the two setups.

- Run simulation for 25 seconds.

## Simulation Setup

- For both AODV and OLSR, we simulate 28 cases with varying numbers of applications. Each case increases the number of applications by one, starting from a single application in Case 1 and going up to 28 applications in Case 28.
- In the NetSim GUI, we provide configuration files for three cases each: AODV and OLSR.
- The complete set of configuration files is available for download at: <https://github.com/NetSim-TETCOS/Manpack-Radio-Scenario-OLSR-AODV-v15.1/archive/refs/heads/main.zip>.

## Results

The following results can be observed from the application metrics in the simulation results window

**Table 4-15:** *Output results of AODV and OLSR Routing simulations.*

| No of Traffic Flows | AODV Throughput (Kbps) | AODV Delay (s) | OLSR Throughput (Kbps) | OLSR Delay (s) |
|---------------------|------------------------|----------------|------------------------|----------------|
| 1                   | 0.16                   | 0.53           | 0.16                   | 0.64           |
| 2                   | 0.16                   | 0.61           | 0.15                   | 1.10           |
| 3                   | 0.16                   | 0.55           | 0.16                   | 0.83           |
| 4                   | 0.16                   | 0.66           | 0.15                   | 0.73           |
| 5                   | 0.16                   | 0.63           | 0.16                   | 0.67           |
| 6                   | 0.16                   | 0.56           | 0.15                   | 0.51           |
| 7                   | 0.15                   | 0.63           | 0.14                   | 0.77           |
| 8                   | 0.15                   | 0.61           | 0.14                   | 0.69           |
| 9                   | 0.16                   | 0.66           | 0.15                   | 0.86           |
| 10                  | 0.16                   | 0.86           | 0.14                   | 1.29           |
| 11                  | 0.16                   | 0.90           | 0.13                   | 1.66           |
| 12                  | 0.16                   | 0.93           | 0.13                   | 1.53           |
| 13                  | 0.16                   | 1.06           | 0.13                   | 1.61           |
| 14                  | 0.14                   | 1.54           | 0.13                   | 1.62           |
| 15                  | 0.14                   | 1.77           | 0.14                   | 1.55           |
| 16                  | 0.15                   | 1.48           | 0.14                   | 1.47           |
| 17                  | 0.14                   | 2.34           | 0.14                   | 1.92           |
| 18                  | 0.13                   | 3.91           | 0.13                   | 2.04           |
| 19                  | 0.11                   | 4.73           | 0.13                   | 2.35           |
| 20                  | 0.10                   | 5.61           | 0.12                   | 2.68           |
| 21                  | 0.08                   | 5.52           | 0.12                   | 2.95           |
| 22                  | 0.08                   | 6.08           | 0.11                   | 3.22           |
| 23                  | 0.07                   | 5.69           | 0.11                   | 3.58           |
| 24                  | 0.07                   | 6.15           | 0.10                   | 3.56           |
| 25                  | 0.07                   | 5.69           | 0.10                   | 3.62           |
| 26                  | 0.07                   | 6.57           | 0.10                   | 3.79           |
| 27                  | 0.06                   | 6.25           | 0.10                   | 4.02           |
| 28                  | 0.05                   | 5.86           | 0.10                   | 3.83           |

**Discussion** The results are analyzed based on how each protocol scales with increasing traffic load, measured by the number of concurrent application flows.

**Delay:**

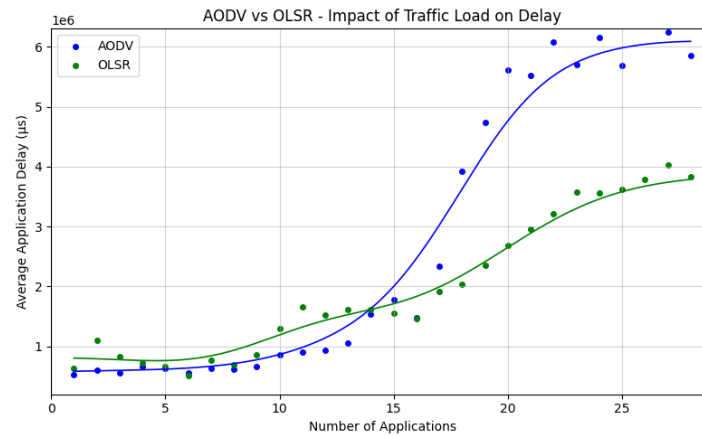


**Figure 4-33:** Comparison of AODV and OLSR – Impact of Traffic Load on Average Delay. Each point in the plot is the output of one simulation run. Kernel regression was used to plot the trend lines.

### Throughput:

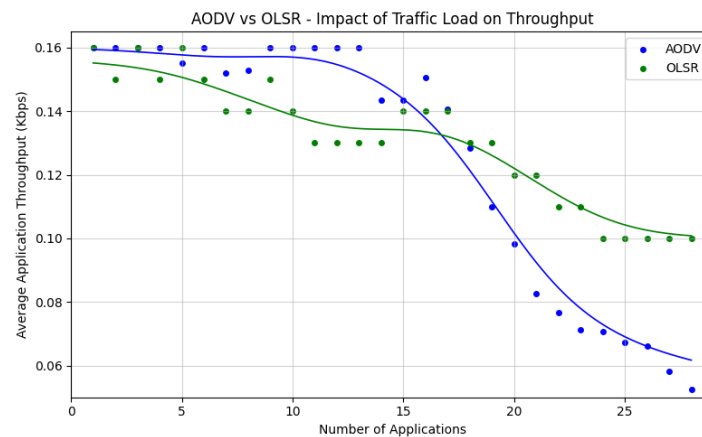


**Figure 4-34:** Comparison of AODV and OLSR – Impact of Traffic Load on Average Throughput.

AODV performs better under low application loads due to its reactive nature, reducing control overhead. However, its performance deteriorates as load increases due to route discovery and maintenance delays.

OLSR, with its proactive routing, maintains consistent route availability and performs better under heavy application loads with lower average delay and relatively higher throughput.

These trends are evident from the plots shown above. AODV initially achieves higher average throughput due to reduced control messaging, but experiences sharp degradation in performance as traffic load increases.

OLSR, on the other hand, maintains moderate but more stable throughput across all traffic loads. Its proactive mechanism ensures routing tables are consistently updated, allowing faster forwarding with lower latency at higher loads. While its overhead may be higher under low load conditions, the proactive design becomes advantageous as traffic density grows.

#### 4.1.6 Tactical vehicular radio network comprising multiple vehicles

Objective: Model, simulate and analyze application throughput and latencies in a tactical vehicular radio network comprising multiple vehicles each transmitting situational awareness, video, and data files.

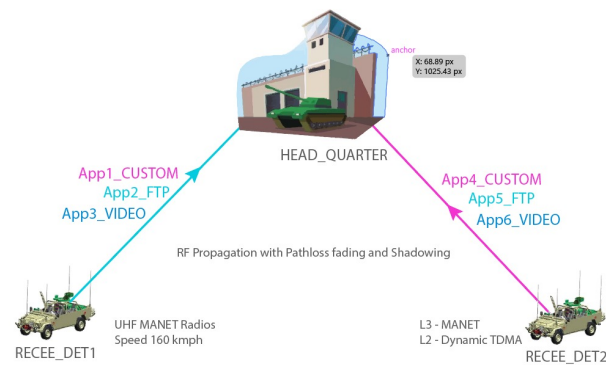


**Figure 4-35:** Representative image of the network scenario under study

Open NetSim and Select **Examples** > **TDMA Radio Networks** > **DTDMA** > **Vehicular Radios** then click on the tile in the middle panel to load the example.

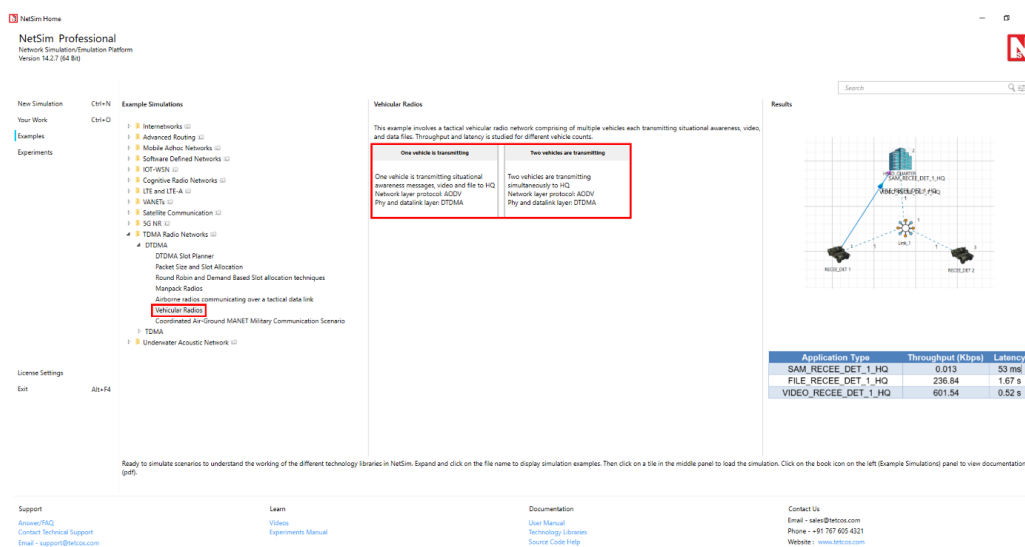


**Figure 4-36:** List of scenarios for the example of Vehicular Radios

One vehicle is transmitting (Case 1): One vehicle is transmitting situational awareness messages, video and file to HQ

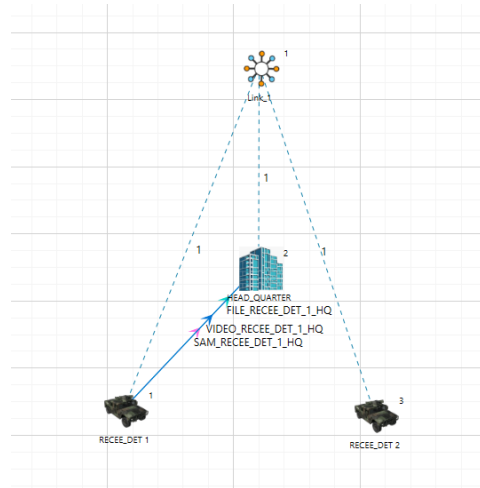


**Figure 4-37:** Network setup for one vehicle transmitting.

## Settings

- Set Grid length as 50km x 25km from grid setting property panel on the right. This needs to be done before any device is placed on the grid.
- In the wireless nodes DTDMA protocol is set in Interface\_1 (Wireless) datalink layer and set the mobility model in position layer as Random Way Point and velocity as 45 m/s (~160 kmph) for Recce (Reconnaissance) detachments and 0m/s for Head Quarter.
- Set the following properties in wireless nodes. To configure any properties in the nodes, click on the node, expand the property panel on the right side, and change the properties as mentioned in the below steps

**Table 4-16:** Datalink and Physical layer properties of wireless nodes

| Device Properties                      |              |
|----------------------------------------|--------------|
| <b>Network layer properties</b>        |              |
| Routing protocol                       | AODV         |
| <b>Interface (Wireless) properties</b> |              |
| <b>Datalink layer properties</b>       |              |
| Slot Duration                          | 10 ms        |
| Frame Duration                         | 12 s         |
| Guard Interval                         | 100 $\mu$ s  |
| Network Type                           | Ad-hoc       |
| Slot Allocation Technique              | Demand based |
| Min and Max slot per device            | 1,5          |
| <b>Physical layer properties</b>       |              |
| Bandwidth                              | 2000 KHz     |
| Data Symbol Rate                       | 2000 kBd     |
| Transmitter Power                      | 20 Watts     |
| Antenna Height                         | 1m           |
| Receiver Sensitivity                   | -113 dBm     |
| Modulation Technique                   | QPSK         |
| Frequency hopping                      | Off          |
| Band                                   | UHF          |
| Lower Frequency                        | 476 MHz      |

- RF Propagation:
- To set the link properties, click on the ad-hoc link, expand the link properties on the right, and set them as follows.

**Table 4-17:** *RF Propagation properties settings*

| Link Properties         |                                   |
|-------------------------|-----------------------------------|
| Channel characteristics | Pathloss and fading and shadowing |
| Pathloss model          | Log distance                      |
| Pathloss exponent       | 2                                 |
| Shadowing model         | Lognormal                         |
| Standard deviation      | 5 dB                              |
| Fading model            | Rayleigh                          |
| Scale parameter         | 1 W                               |

- Application Traffic settings (HQ communicating with two vehicular Recce detachments): To create any traffic, click on the “Set Traffic” tab in the ribbon at the top and configure the traffic as described. To set the other application properties, click on the created application, expand the application property panel on the right, and set the properties as specified.

**Table 4-18:** *SAM RECEE DET 1 HQ Application properties*

| SAM RECEE DET 1 HQ (Situational Awareness Messages) |                                  |
|-----------------------------------------------------|----------------------------------|
| Application type                                    | Custom                           |
| Application name                                    | SAM RECEE DET 1 HQ               |
| Source ID                                           | Node 1                           |
| Destination ID                                      | Node 2                           |
| Transport protocol                                  | UDP                              |
| QoS                                                 | BE                               |
| Packet Size                                         | 79 Bytes                         |
| IAT                                                 | 60,000,000 $\mu$ s (60s = 1 min) |

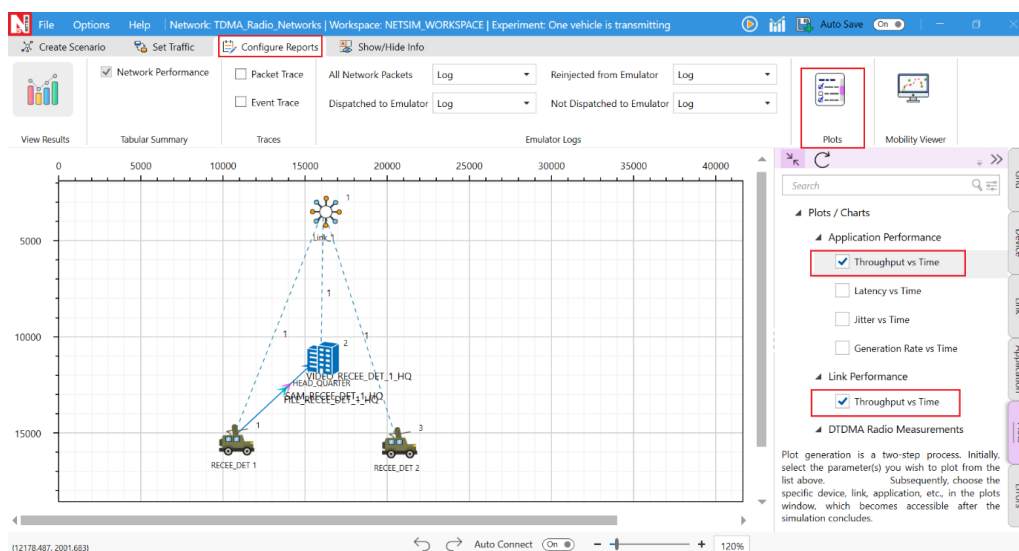
**Table 4-19:** *FILE RECEE DET 1 HQ application properties*

| FILE RECEE DET 1 HQ |                             |
|---------------------|-----------------------------|
| Application type    | FTP                         |
| Application name    | FILE RECEE DET 1 HQ         |
| Source ID           | Node 1                      |
| Destination ID      | Node 2                      |
| Start time          | 5 s                         |
| Transport protocol  | UDP                         |
| QoS                 | BE                          |
| File size           | 562500 Bytes = 4.5 Megabits |
| IAT                 | 20 s (60s = 1 min)          |

**Table 4-20:** VIDEO RECEE DET 1 HQ application properties

| VIDEO RECEE DET    |                                                  |
|--------------------|--------------------------------------------------|
| Application type   | Video                                            |
| Application name   | VIDEO RECEE DET 1 HQ                             |
| Source ID          | Node 1                                           |
| Destination ID     | Node 2                                           |
| Model type         | Independent gaussian                             |
| Frame per sec      | 20                                               |
| Pixel per frame    | 60000                                            |
| Transport protocol | UDP                                              |
| QoS                | NRTPS                                            |
| Mu                 | 0.5                                              |
| Sigma              | 0.23                                             |
| Generation rate    | $= fps \times ppf \times \mu = 0.6 \text{ Mbps}$ |

- To enable plots, click on configure reports tab ▸ Plots ▸ select application and link plots as shown below

**Figure 4-38:** Enabling the Plots for One vehicle is transmitting scenario.

- Run the simulation for 100 sec.

Two vehicles are transmitting (Case 2): Two vehicles are transmitting simultaneously to HQ

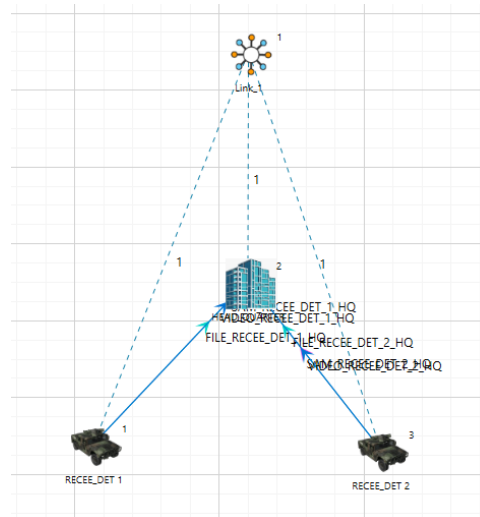


**Figure 4-39:** Network setup for two vehicles transmitting.

## Settings

- Consider Case 1. Additionally, create three more applications from Node 3 to Node 2. Refer to the tables above for application properties
- Run simulation for 100 sec.

## Results and Discussion

One vehicle transmitting (Case 1)

**Table 4-21:** Results Comparison

| Application Type     | Throughput (Kbps) | Latency (seconds) |
|----------------------|-------------------|-------------------|
| SAM_RECEE_DET_1_HQ   | 0.013             | 0.05              |
| FILE_RECEE_DET_1_HQ  | 236.84            | 1.67              |
| VIDEO_RECEE_DET_1_HQ | 597.77            | 0.51              |

To Observe the throughput plots for the simulated scenario, click on Throughput vs Time plot from under plots as shown below and select the desired application, disable Accelerate Plotting and click on plot.

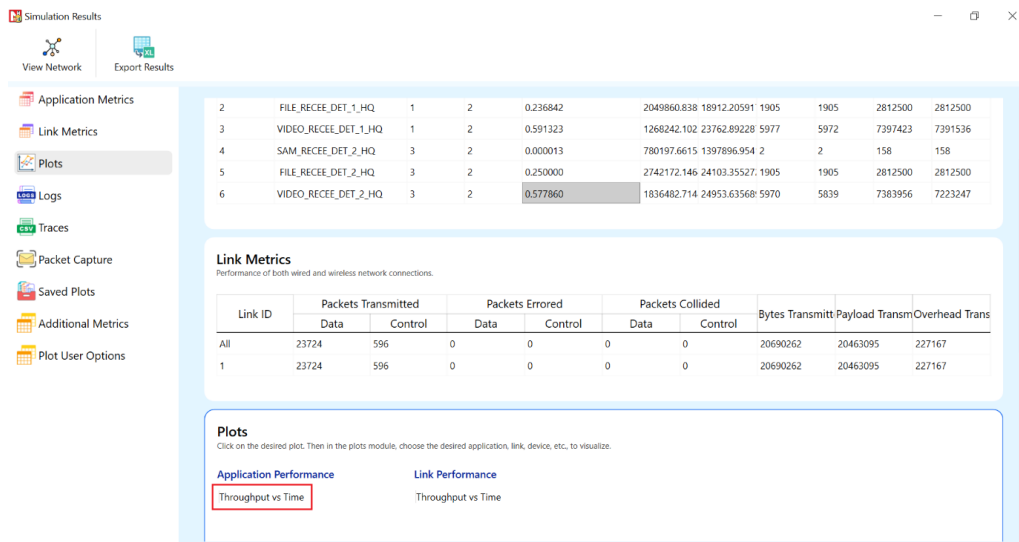


**Figure 4-40:** Opening Throughput vs Time plot from Results window.

Throughput vs time plot (FTP Application):

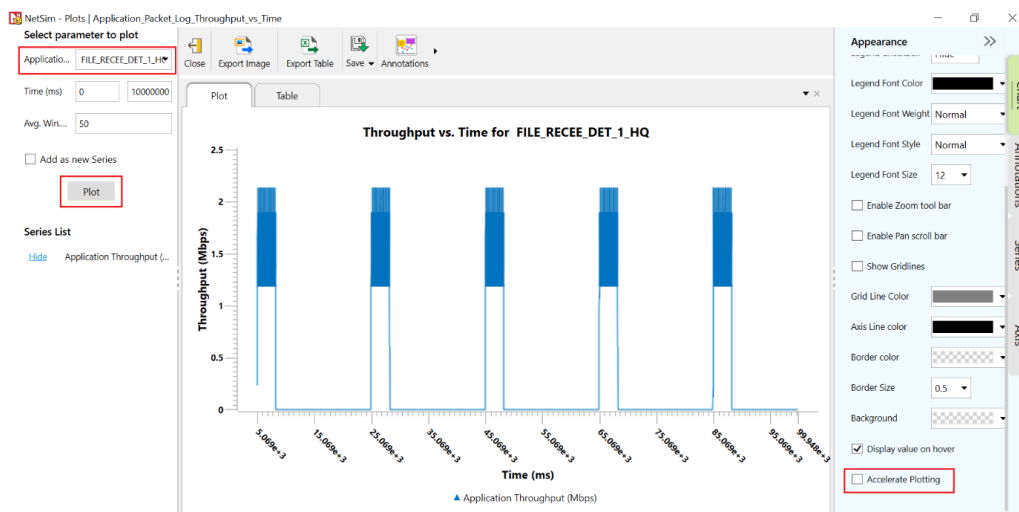


**Figure 4-41:** Throughput vs. time plot for FTP Application

Throughput vs time plot (Video Application):

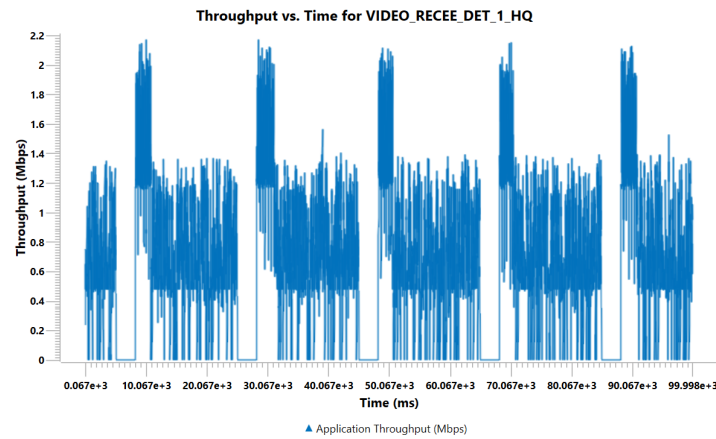


**Figure 4-42:** *Throughput vs. time plot for Video Application*

Throughput vs Time Plot (Link\_1):

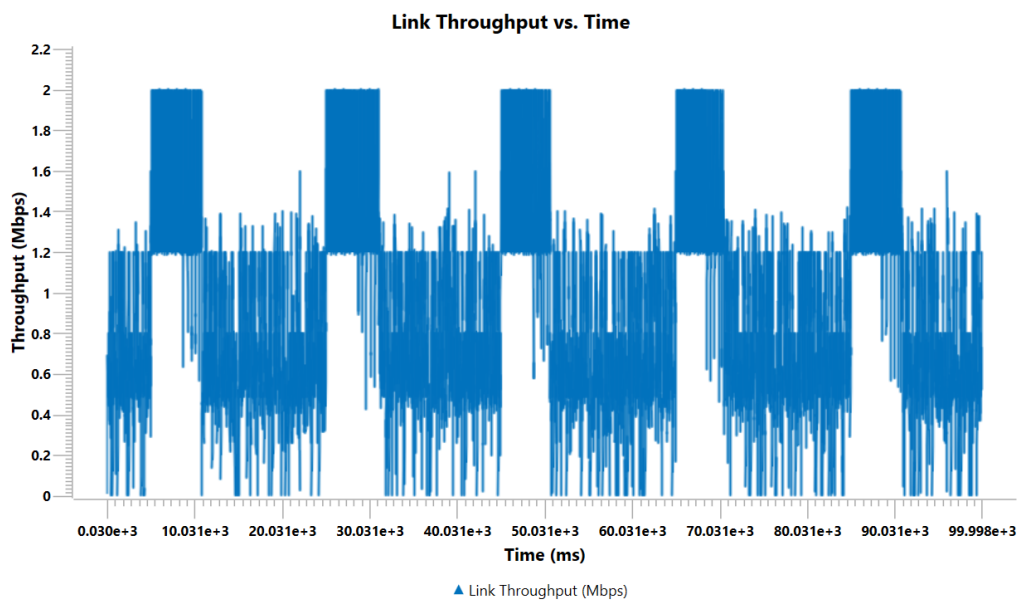


**Figure 4-43:** *Plot of Throughput vs. Time for Link\_1*

The start time for FILE RECEE DET 1 HQ is 5 s. We see in the Throughput vs Time plot for FILE RECEE DET 1 HQ application, that at the 5th second, the file transmission starts and gets a throughput of approximately 2 Mbps. The file size is 562500 B or 2.6 Megabits, and with a throughput of 2 Mbps it takes about 2.8 s for this file to be transferred. Therefore, the throughput drops at around 9 s since the file transfer is completed by then. The file inter arrival time is 20s, and this means the next (2nd) file is generated and transmitted at 25th second (the first file starts at 5s and to this add the inter-file time of 20s). At the 25th second again the file transmission starts, takes around 2.8s for transmission, and is completed around 28.3 s. The same cycle continues.

Now let us turn to the Throughput vs Time Plot for the Video application. This application starts at 0 s and gradually it sees a throughput of about 600 Kbps, which is equal to the generation rate. This means the network has sufficient capacity to transmit the video. Note that when the FTP application starts at 5 s, it gets priority for transmission and the video throughput drops to 0. The FTP application transmission is completed at 10s. At this point the video transmission resumes. The throughput goes up to about 2 Mbps since the buffered video frames are being sent. At around 18th second all the buffered frames have been sent and the video rate drops back to 600 Kbps which is equal to the generation rate.

The link which has a capacity of 2 Mbps initially sees about 600 Kbps of occupancy. Once the FTP

application starts, the link occupancy goes up to 2 Mbps. After the file is transferred in the FTP application, the link occupancy starts reducing since it is only video that is now being transmitted.

Two vehicles transmitting (Case 2)

**Table 4-22:** *Results Comparison*

| Application Type     | Throughput (Kbps) | Latency (Seconds) |
|----------------------|-------------------|-------------------|
| SAM RECEE DET 1 HQ   | 0.013             | 0.09              |
| FILE RECEE DET 1 HQ  | 236.84            | 2.04              |
| VIDEO RECEE DET 1 HQ | 597.38            | 1.25              |
| SAM RECEE DET 2 HQ   | 0.013             | 0.50              |
| FILE RECEE DET 2 HQ  | 250.00            | 2.74              |
| VIDEO RECEE DET 2 HQ | 575.52            | 1.84              |

**Plot Results** To Observe the throughput plots for the simulated scenario, click on Throughput vs Time plot from under plots as shown below and select the desired application, disable Accelerate Plotting and click on plot.

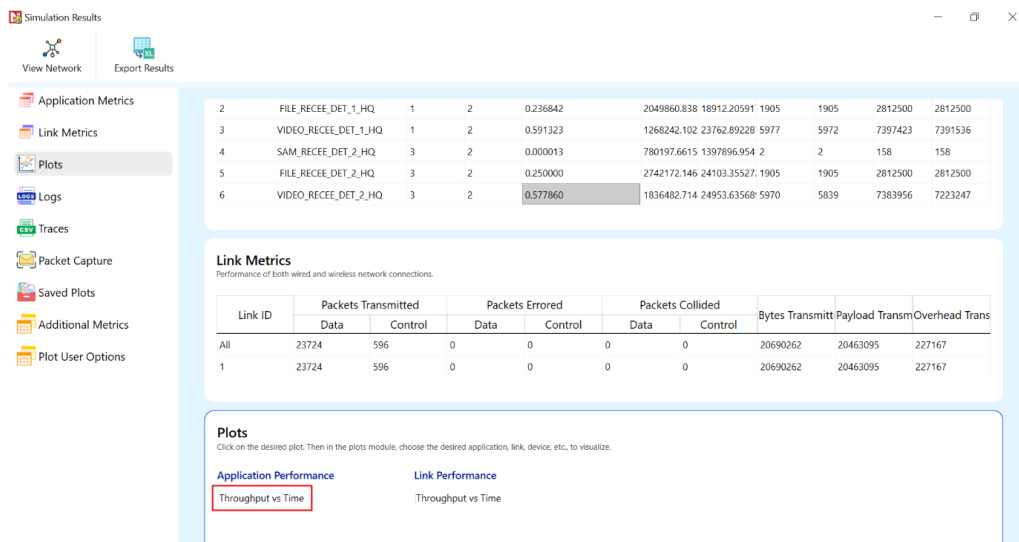


**Figure 4-44:** *Opening the Throughput vs Time plot from Results window.*

Throughput vs time plot (Application – FTP 1)

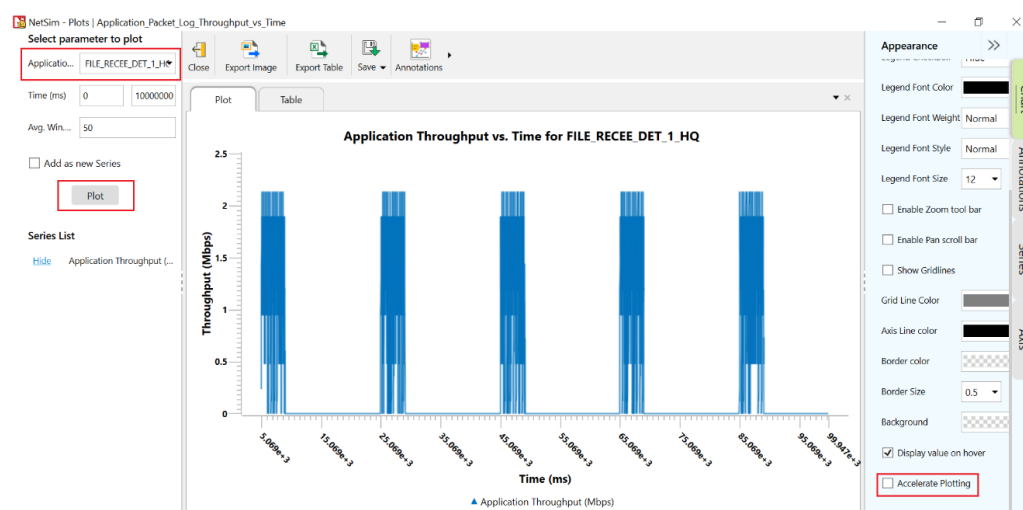


**Figure 4-45:** *Throughput vs. time plot for FTP 1 Application*

Throughput vs time plot (Application – Video 1)

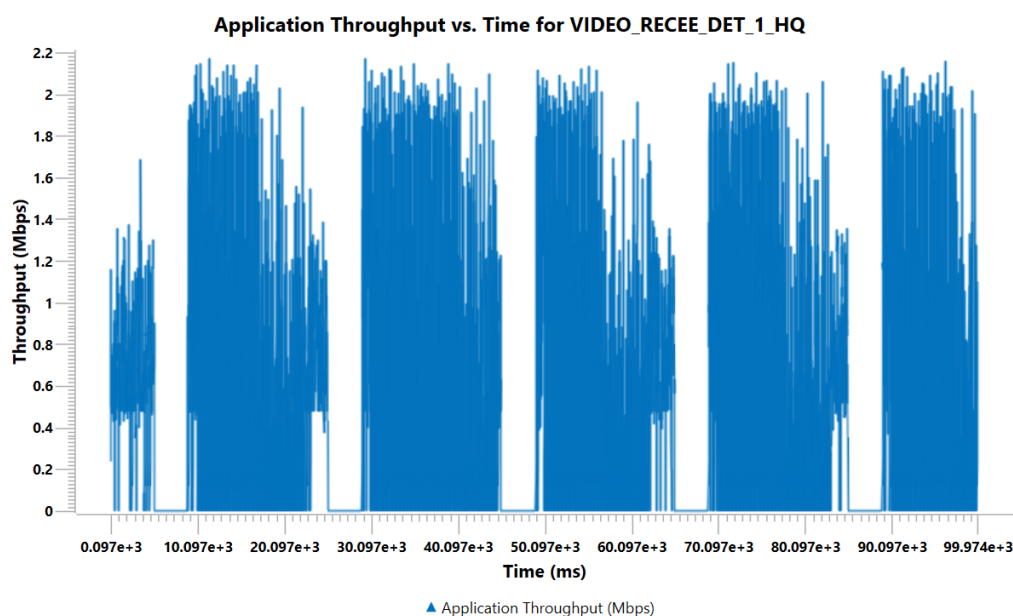


**Figure 4-46:** *Throughput vs. time plot for Video 1 Application*

Throughput vs time plot (Application – FTP 2)

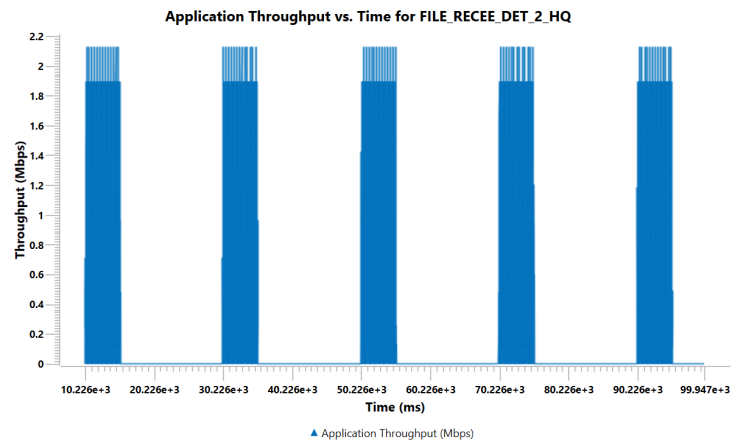


**Figure 4-47:** *Throughput vs. time plot for FTP 2 Application*

Throughput vs time plot (Application – Video 2)

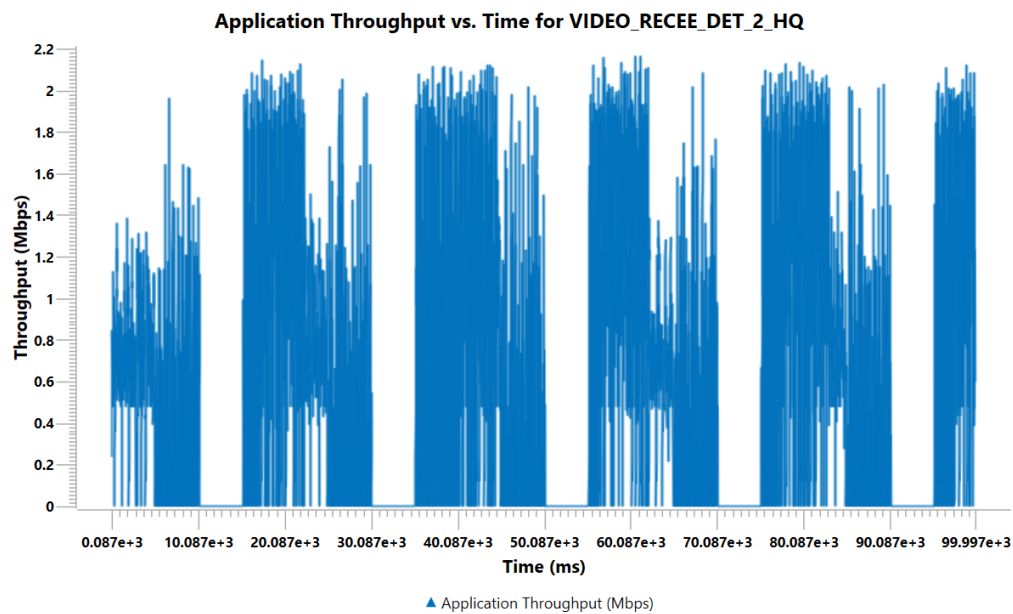


**Figure 4-48:** *Throughput vs. time plot for Video 2 Application*

Throughput vs Time Plot (Link 1)

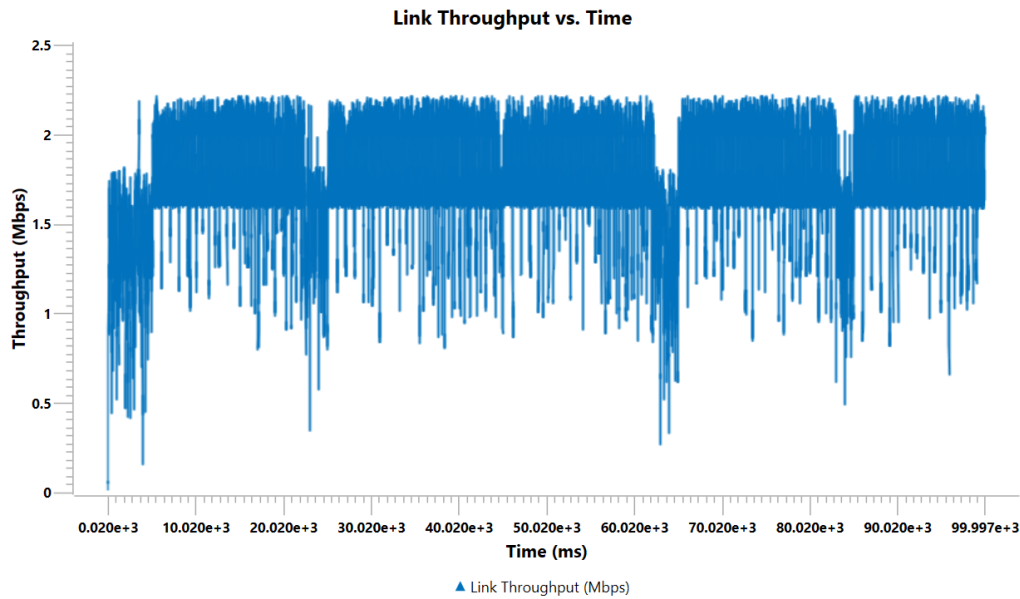


**Figure 4-49:** *Plot of Throughput vs. Time for Link 1*

We compare the results of two vehicles transmitting simultaneously (case 2), with a single vehicle transmission (case 1). At time 0s, both vehicles start their video transmissions. In case 1 the approximate video transmission throughput was 600 Kbps. In case 2, each video gets a video transmission throughput of 600 Kbps initially, or a total system throughput of 1.2 Mbps. This is possible since the Phy capacity of the link is 2 Mbps.

Now the FILE RECEE DET 1 HQ starts at the 5th second, while the FILE RECEE DET 2 HQ starts at the 10th second. Each of these applications send a file of size 4.5 Megabits every 20s which equals an average FTP generation rate of 225 Kbps. As soon as FILE RECEE DET 1 HQ starts in Vehicle 1, it is given priority over the video transmission from the same vehicle. Therefore, the throughput of Video 1 drops immediately. Note that in case 1, FTP application saw an instantaneous throughput of about 2 Mbps whereas in case 2, it is only able to get a throughput of  $\sim 1900$  Kbps. This is because some of the slots on the link are being allocated to Video 2 application. Therefore the 4.5 Mbit file takes  $\sim 4$ s to transfer, as opposed to 2.8s in case 1. This in turn means that the video 1 application will start getting transmitted (after being buffered) only from around 9 s (5s plus 4s). In case 1 the video started getting transmitted from 9.5s itself.

Next, let us study the application throughputs for the transmissions from the second vehicle. Similar to the first vehicle video starts at 0s and sees a throughput of 600 Kbps till the 5th second. At this time FTP 1 starts, and this leads to a slight drop in Video 2, since the DTDMA protocol starts assigning more slots to FTP 1 application. FTP 2 starts from the 10th second. At this point in time, FTP 2 gets higher priority over Video 2 (since both are being transmitted from the same vehicle). Therefore, the throughput of video 2 drops to zero. Similar to FTP 1, FTP 2 also see a throughput of  $\sim 2$  Mbps, and hence it also takes  $\sim 4$ s to transfer each file. Once this file is transmitted, Video 2 again starts seeing a throughput of  $\sim 1.5$  Mbps.

The Video application throughput of 2 Mbps in between the file transfers. This is because of video packets getting buffered. Video is being continuously generated at 600 Kbps, but there is packet buffering during the time when the FTP application is being sent. This cycle repeats.

As compared to case 1, where the link was not fully occupied, in case 2, we see the link if fully utilized and the link throughput is at 2 Mbps. In fact, the combined generation rate of the 2 FTP and 2 Video application is greater than 2 Mbps. It is for this reason that the situational awareness application sees a latency of 0.09 s as against 0.05 ms.

This example can be further extended to study the impact of other variations such as propagation losses, round robin slot allocation etc.

### 4.1.7 Coordinated Air-Ground MANET Military Communication Scenario

#### Objective

To analyze connectivity, signal quality and throughput for a MANET military communication scenario comprising airborne and ground platforms.

#### Network Setup

Open NetSim and Select **Examples** ▸ **TDMA Radio Networks** ▸ **DTDMA** ▸ **Coordinated Air-Ground MANET Military Communication Scenario** then click on the tile in the middle panel to load the example as shown.

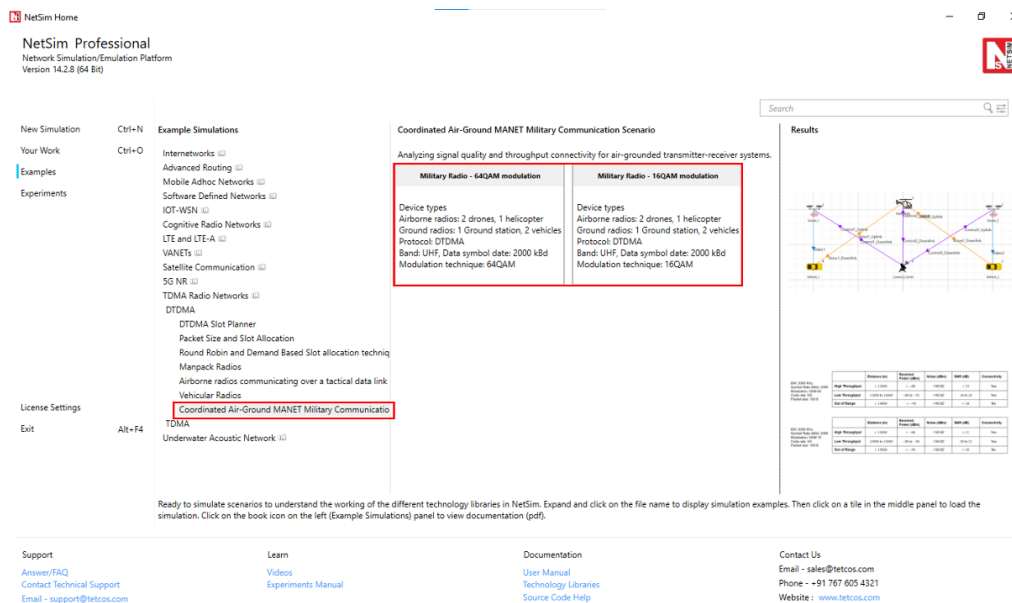


**Figure 4-50:** List of scenarios for the example of Coordinated Air-Ground MANET Military Communication Scenario.

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

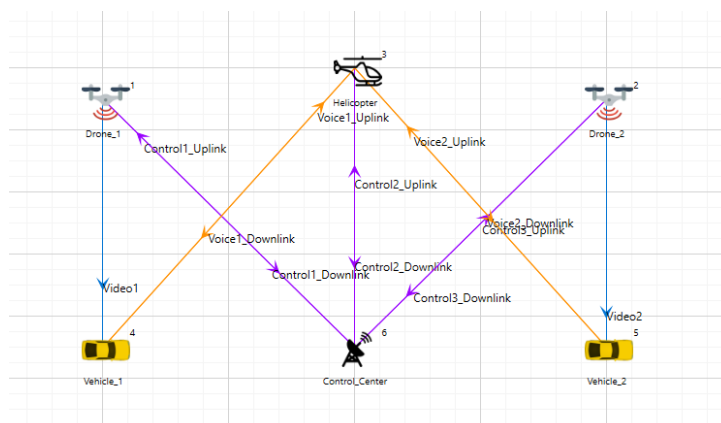


**Figure 4-51:** Network set up for studying this example.

The scenario comprises:

- Three (3) airborne radios; 2 drones and 1 helicopter.

- Three (3) ground radios; 1 ground station and 2 mobile platforms (e.g., vehicles)

The traffic pattern in the network is as follows:

- All 3 airborne radios send/receive control messages to/from the ground station. This is modeled as short 100B packets sent/received every 500 ms.
- The 2 drones send video traffic to the 2 mobile platforms at a rate of 4 Mbps; each drone transmits to one vehicle.
- The 2 vehicles and the helicopter use two voice communications at a rate of 64 Kbps.

## Device configurations

- Right click on device properties ▷ Physical layer ▷ under DTDMA protocol the following changes were done.

**Table 4-23:** *Device properties settings*

| PHY layer settings         |                 | Routing                        |                             |
|----------------------------|-----------------|--------------------------------|-----------------------------|
| Bandwidth (KHz)            | 2000            | Hops                           | 1(Single hop)               |
| Data symbol rate (kBd)     | 2000            | Routing                        | Static route configurations |
| Receiver Sensitivity (dBm) | -97             | <b>Channel model</b>           |                             |
| Modulation Technique       | 64QAM and 16QAM |                                |                             |
| Coding Rate                | 5/6 and 3/4     |                                |                             |
| Band                       | UHF             |                                |                             |
| Lower Freq. (MHz)          | 300             |                                |                             |
|                            |                 | Pathloss model                 | Log distance                |
|                            |                 | Pathloss exponent ( $\alpha$ ) | 2.65                        |

- Application settings for drone, vehicles, and control system communication

| Control system application settings |      |
|-------------------------------------|------|
| Application type                    | CBR  |
| Packet size (byte)                  | 100  |
| Inter Arrival Time ( $\mu$ s)       | 8000 |
| Mean generation rate (kbps)         | 100  |

**Table 4-24:** *Settings for Control system applications*

**Table 4-25:** *Settings for Video application*

| Video application settings           |       |
|--------------------------------------|-------|
| Application type                     | Video |
| Frame per sec                        | 100   |
| Pixel per frame                      | 40000 |
| Mean, Bits Per Pixel ( $\mu$ s)      | 1     |
| Std Dev, Bits Per Pixel ( $\sigma$ ) | 0.23  |
| Mean generation rate (Mbps)          | 4     |

**Table 4-26:** *Settings for Voice application*

| Voice application settings    |       |
|-------------------------------|-------|
| Application type              | Voice |
| Codec                         | G.711 |
| Packet size (byte)            | 160   |
| Inter Arrival Time ( $\mu$ s) | 20000 |
| Mean generation rate (kbps)   | 64    |

- Both uplink and downlink control applications are configured between
  - Control center and Drones.
  - Control center and Helicopter.
- Video applications are configured between
  - Drone 1 to Vehicle 1
  - Drone 2 to Vehicle 2
- Both uplink and downlink voice applications are configured between
  - Helicopter and Vehicle 1.
  - Helicopter and Vehicle 2

## Mobility

- Drones move in a circular path along X-Y. The drones' height ( $z$ ) = 100 m and doesn't change with time.
- The helicopter moves randomly along X-Y. The helicopter height ( $z$ ) = 150 m and doesn't change with time.
- Vehicle 1 moves Left to Right (West to East)
- Vehicle 2 moves Top to Bottom (North to South)
- The mobility pattern input to the mobility file for 64-QAM is given below. The same approach can be applied to the 16-QAM example, which includes both in-range and out-of-range cases.

**Table 4-27:** *Mobility.csv file inputs.*

| #Time(s) | Device ID | X (m)    | Y (m)   | Z (m) |
|----------|-----------|----------|---------|-------|
| 0        | 1         | 16045.08 | 2061.07 | 100   |
| 10       | 1         | 17000    | 5000    | 100   |
| 20       | 1         | 16045.08 | 7938.93 | 100   |
| 30       | 1         | 13545.08 | 9755.28 | 100   |
| 40       | 1         | 10454.92 | 9755.28 | 100   |
| 50       | 1         | 7954.92  | 7938.93 | 100   |
| 60       | 1         | 7000     | 5000    | 100   |
| 70       | 1         | 7954.92  | 2061.07 | 100   |
| 80       | 1         | 10454.92 | 244.72  | 100   |
| 90       | 1         | 13545.08 | 244.72  | 100   |
| 100      | 1         | 16045.08 | 2061.07 | 100   |
| 0        | 2         | 26454.92 | 244.72  | 100   |
| 10       | 2         | 29545.08 | 244.72  | 100   |
| 20       | 2         | 32045.08 | 2061.07 | 100   |
| 30       | 2         | 33000    | 5000    | 100   |
| 40       | 2         | 32045.08 | 7938.93 | 100   |
| 50       | 2         | 29545.08 | 9755.28 | 100   |

| #Time(s) | Device ID | X (m)    | Y (m)   | Z (m) |
|----------|-----------|----------|---------|-------|
| 60       | 2         | 26454.92 | 9755.28 | 100   |
| 70       | 2         | 23954.92 | 7938.93 | 100   |
| 80       | 2         | 23000    | 5000    | 100   |
| 90       | 2         | 23954.92 | 2061.07 | 100   |
| 100      | 2         | 26454.92 | 244.72  | 100   |
| 0        | 4         | 6000     | 15000   | 0     |
| 10       | 4         | 7000     | 15000   | 0     |
| 20       | 4         | 8000     | 15000   | 0     |
| 30       | 4         | 9000     | 15000   | 0     |
| 40       | 4         | 10000    | 15000   | 0     |
| 50       | 4         | 11000    | 15000   | 0     |
| 60       | 4         | 12000    | 15000   | 0     |
| 70       | 4         | 13000    | 15000   | 0     |
| 80       | 4         | 14000    | 15000   | 0     |
| 90       | 4         | 15000    | 15000   | 0     |
| 100      | 4         | 16000    | 15000   | 0     |
| 0        | 5         | 28000    | 11000   | 0     |
| 10       | 5         | 28000    | 12000   | 0     |
| 20       | 5         | 28000    | 13000   | 0     |
| 30       | 5         | 28000    | 14000   | 0     |
| 40       | 5         | 28000    | 15000   | 0     |
| 50       | 5         | 28000    | 16000   | 0     |
| 60       | 5         | 28000    | 17000   | 0     |
| 70       | 5         | 28000    | 18000   | 0     |
| 80       | 5         | 28000    | 19000   | 0     |
| 90       | 5         | 28000    | 20000   | 0     |
| 100      | 5         | 28000    | 21000   | 0     |
| 0        | 3         | 20000    | 4000    | 150   |
| 10       | 3         | 20000    | 6000    | 150   |
| 20       | 3         | 20000    | 8000    | 150   |
| 30       | 3         | 20000    | 10000   | 150   |
| 40       | 3         | 19000    | 4000    | 150   |
| 50       | 3         | 19000    | 6000    | 150   |
| 60       | 3         | 19000    | 8000    | 150   |
| 70       | 3         | 19000    | 10000   | 150   |
| 80       | 3         | 21000    | 4000    | 150   |
| 90       | 3         | 21000    | 6000    | 150   |
| 100      | 3         | 21000    | 8000    | 150   |

- The movement patterns for vehicles, helicopters, and drones, can be visualized using the Python script available in <https://github.com/NetSim-TETCOS/Mobility-Plot-3D/archive/refs/heads/main.zip>.
- In the Python script, the user may need to adjust the log file path to match the temporary path of NetSim and then run the script to generate the mobility pattern, as shown below.

```

C:\Users\user\Downloads\Mobility-Plot-3D-main\Mobility-Plot-3D-main\Mobility-Plot-3D-main\Main.py - Sublime Text (LARGE TEXT)
File Edit Selection Find View Goto Tools Project Preferences Help
Python3
1 import pandas as pd
2 import matplotlib.pyplot as plt
3 from mpl_toolkits.mplot3d import Axes3D # Importing 3D axes
4
5 # Path of the mobility log file from temp path
6 log_file_path = "C:\\Users\\MARK\\AppData\\Local\\Temp\\netsim\\pro_3d_1\\log\\Mobility_log.csv"
7
8 # Load data from the file, skipping the first row containing column headers
9 data = pd.read_csv(log_file_path)
10
11 # Define device names array (modify as needed)
12 device_names = ['Drone 1', 'Drone 2', 'Helicopter', 'Vehicle 1', 'Vehicle 2', 'Control Center']
13
14 device_ids = data['Device ID'].unique() # Unique device IDs
15 num_devices = len(device_ids) # Number of devices
16
17 # Create a 3D plot
18 fig = plt.figure(figsize=(10, 8))
19 ax = fig.add_subplot(111, projection='3d')
20
21 # Color map for devices
22 colors = plt.cm.tab10(range(num_devices))
23
24 line_width = 1.5
25
26 for i, device_id in enumerate(device_ids):
27     # Data for a particular device
28     device_data = data[data['Device ID'] == device_id]
29     x = device_data['Position X(m)'] / 1000 # X coordinates
30     y = device_data['Position Y(m)'] / 1000 # Y coordinates
31     z = device_data['Position Z(m)'] # Z coordinates
32

```

**Figure 4-52:** Changes made to the log file path for the Python mobility script

### Vehicle, Drone, and Helicopter Movement Patterns

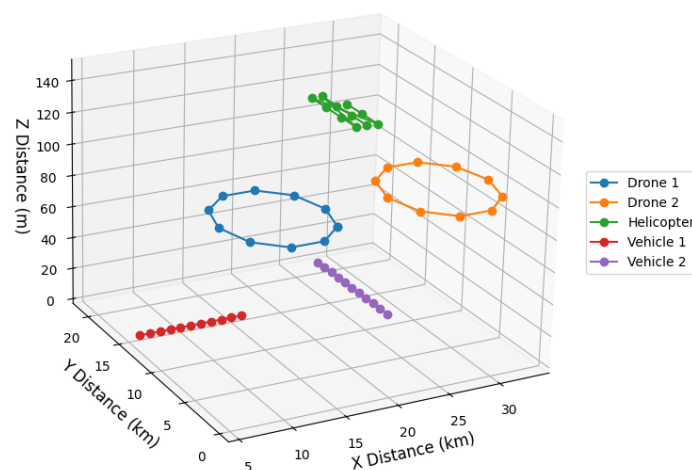


**Figure 4-53:** The drones move in a circular path along X-Y at a height of 100 m. The helicopter moves randomly along X-Y at a height of 150 m. Vehicle 1 moves left to right (west to east), and Vehicle 2 moves top to bottom (north to south)

- On the Right-hand side plots tab, click on plots and enable the Application throughput vs time & SINR plots under network plots and also enable the DTDMA, application packet flow and mobility logs under the network logs in the configure reports tab as shown below.

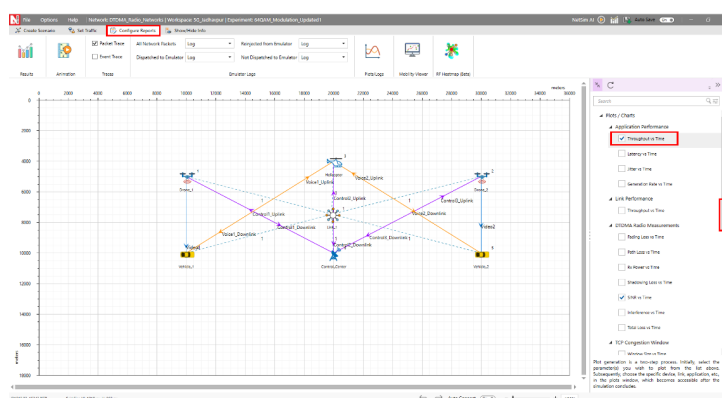


**Figure 4-54:** Enabling plots and logs in NetSim GUI.

- Set the simulation time as 101 sec and simulate.
- For case 2, follow the same steps with the modulation technique set to 16QAM.

**Results and Analysis** The following plots show ‘throughput versus time’ and ‘SINR versus time’ for various applications. We can observe three distinct operational states:

- A ‘connected’ state with high SINR, yielding high throughput.
- A ‘connected’ state with low SINR, resulting in reduced throughput.
- A ‘disconnected’ state, characterized by an SINR too low to maintain a link

**NOTE:** Disable the Accelerate Plotting option in the plots and keep Window size = 1000ms as shown in figure below

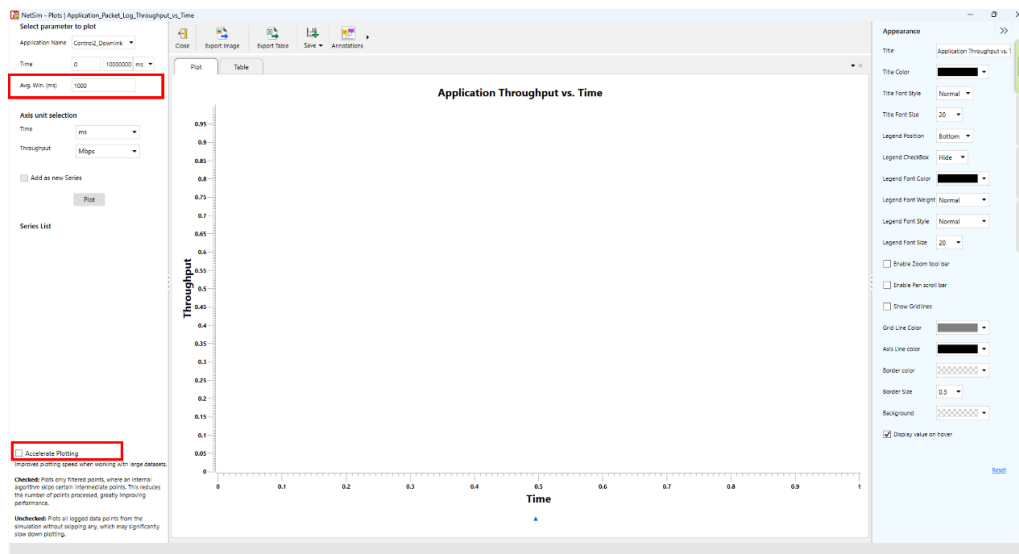


**Figure 4-55:** Disable Accelerate Plotting & Window Size=1000ms

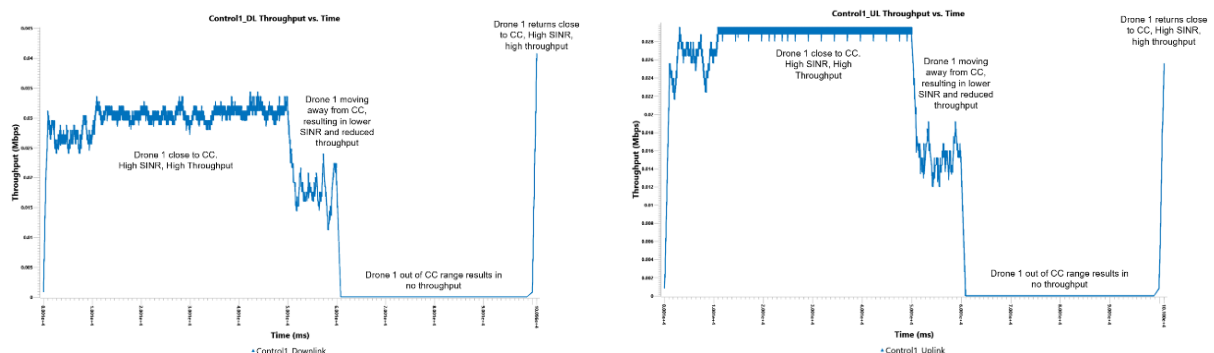


**Figure 4-56:** Drone-1 to Control Centre (uplink and downlink) – Throughput vs. Time

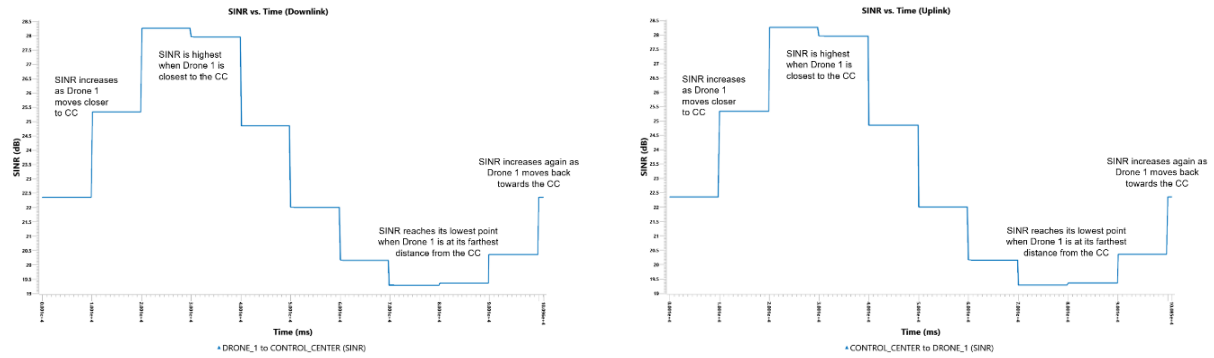


**Figure 4-57:** *Drone-1 to Control Centre (UL and DL) – SNR vs. Time*

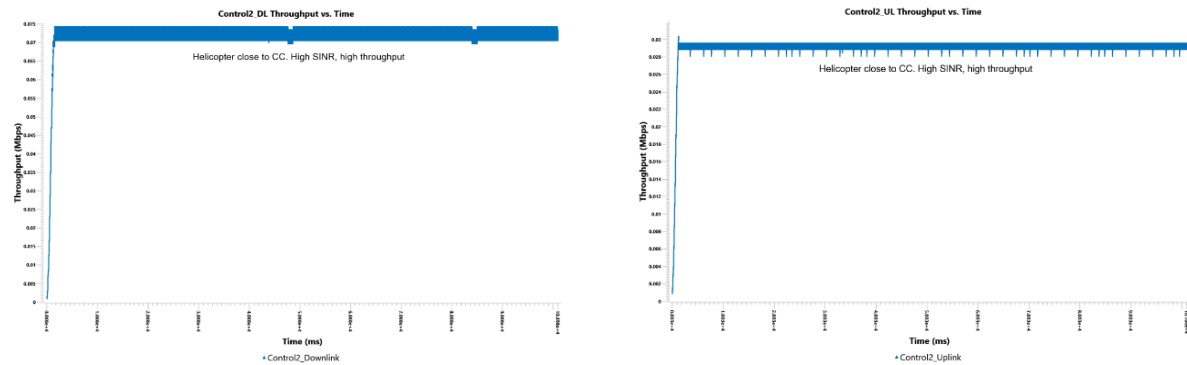


**Figure 4-58:** *Helicopter to Control Centre (uplink and downlink) – Throughput vs. Time*

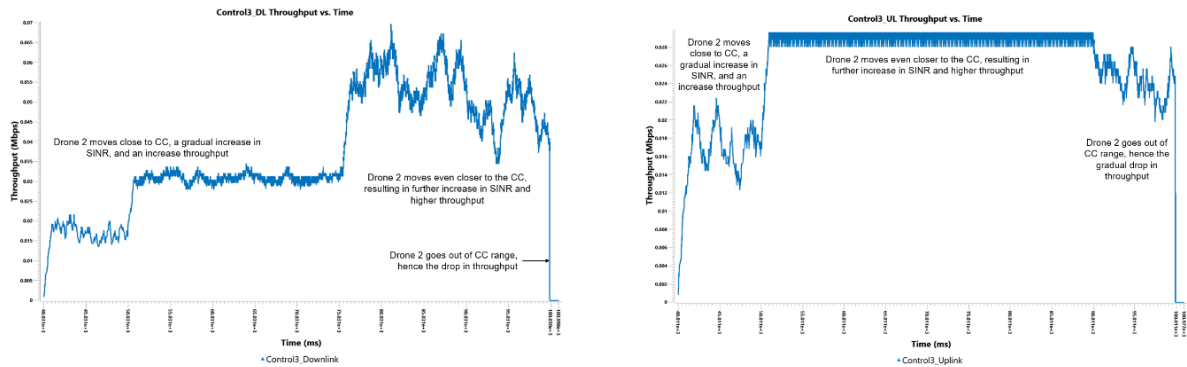


**Figure 4-59:** *Drone-2 to Control Centre (uplink and downlink) – Throughput vs. Time*

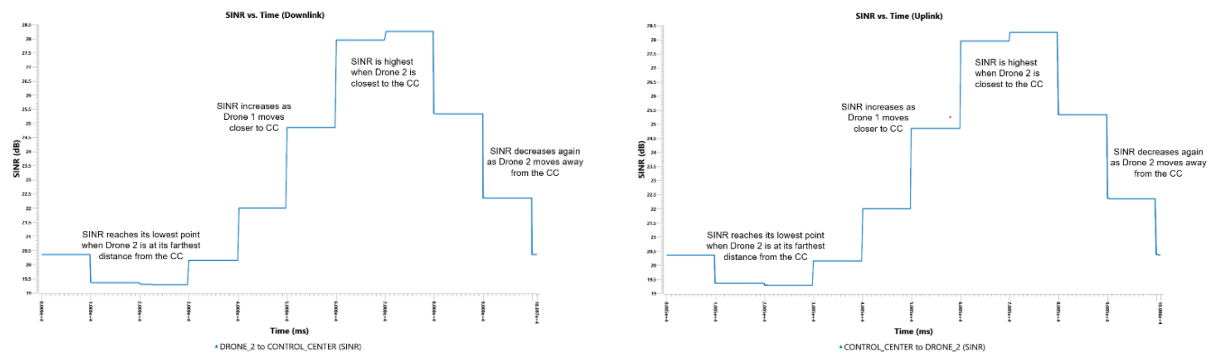


**Figure 4-60:** *Drone-2 to Control Centre (UL and DL) – SNR vs. Time*

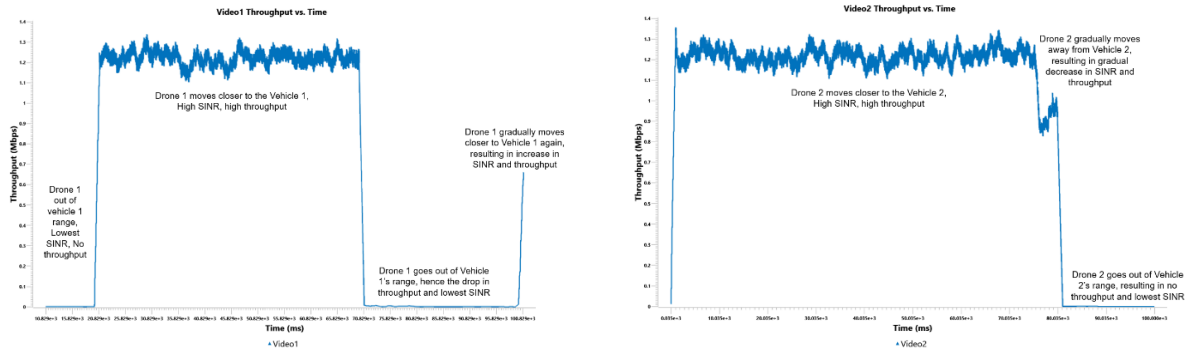


**Figure 4-61:** Drone-1 to Vehicle-1 and Drone-2 to Vehicle-2 – Throughput vs. Time

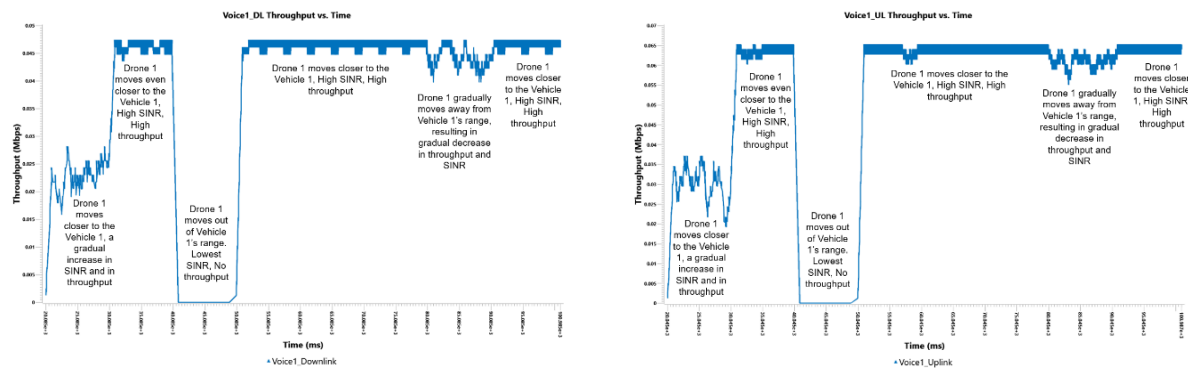


**Figure 4-62:** Helicopter to Vehicle 1 (uplink and downlink) – Throughput vs. Time

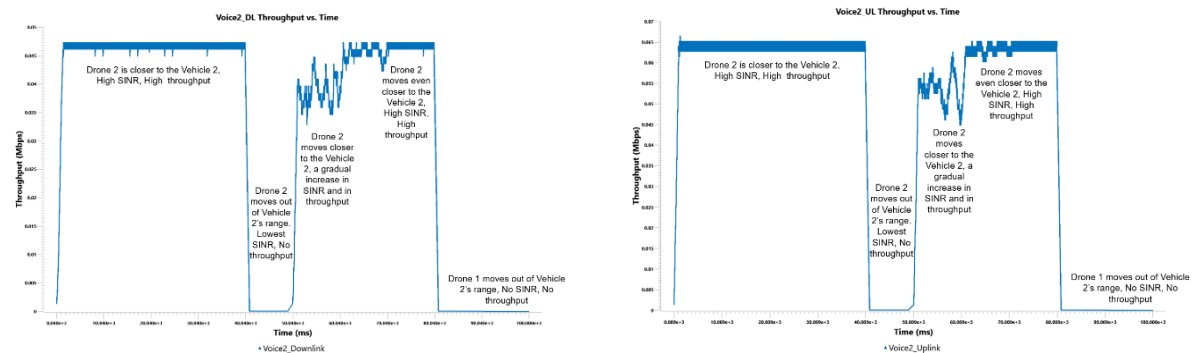


**Figure 4-63:** Helicopter to Vehicle-2 (uplink and downlink) – Throughput vs. Time

**Table 4-28:** Results of Case 1 Symbol Rate (kBd) 2000; Modulation 64-QAM; Coding Rate 5/6.

|                 | Distance<br>(m) |  | Received<br>Power (dBm) | Noise<br>(dBm) | SNR<br>(dB) | Connectivity | Sum<br>Throughput<br>(Mbps) |
|-----------------|-----------------|--|-------------------------|----------------|-------------|--------------|-----------------------------|
| High Throughput | < 9000          |  | > -83                   | -140.82        | > 27        | Yes          | 1.88                        |
| Low Throughput  | 10000 to 17000  |  | -85 to -91              | -140.82        | 20 to 26    | Yes          |                             |
| Out of Range    | > 17000         |  | < -91                   | -140.82        | < 20        | No           |                             |

**Table 4-29:** Results of Case 2 Symbol Rate (kBd) 2000; Modulation 16-QAM; Coding Rate 3/4.

|                 | Distance<br>(m) |  | Received<br>Power (dBm) | Noise<br>(dBm) | SNR<br>(dB) | Connectivity | Sum<br>Throughput<br>(Mbps) |
|-----------------|-----------------|--|-------------------------|----------------|-------------|--------------|-----------------------------|
| High Throughput | < 20000         |  | > -93                   | -140.82        | > 18        | Yes          | 1.08                        |
| Low Throughput  | 20000 to 26000  |  | -93 to -96              | -140.82        | 15 to 18    | Yes          |                             |
| Out of Range    | > 27000         |  | < -95                   | -140.82        | < 15        | No           |                             |

**Results: Distance – SNR – Connectivity for 64-QAM and 16-QAM** The table outlines performance thresholds for a network with a fixed symbol rate of 2000 kBd under QAM 64 and QAM 16 modulations.

- In QAM 64, high throughput is sustained below 9000 meters with received power above -93 dBm and SINR exceeding 27 dB. Low throughput is noted between 10,000 to 17,000 meters with received power from -85 to -91 dBm and SINR between 20 to 26 dB. Connectivity fails past 17,000 meters, where received power dips below -91 dBm and SINR falls under 20 dB.
- Lowering the modulation to QAM 16 extends the high and low throughput ranges to 20,000 and 26,000 meters, respectively, with a slight reduction in SINR requirements for high throughput to above 18 dB and for low throughput between 15 to 18 dB. The network is out of range beyond 27,000 meters, with received power below -95 dBm and SINR less than 15 dB.

#### 4.1.8 Optimized slot allocation for load balancing in dynamic TDMA based MANETs

**Introduction** In wireless multi-hop networks, the slot-to-node allocation schedule has a significant impact on network performance. While traditional Round-Robin slot allocation has been widely used due to its simplicity, allocating one slot per node sequentially, it fails to account for the complex dynamics of modern wireless networks where nodes serve multiple roles - as sources, relays, and destinations. This limitation becomes particularly significant in networks with varying hop counts, where some nodes act as critical relay points for multiple traffic flows.

This study introduces and evaluates a Load-Based slot allocation strategy that dynamically assigns resources based on node roles and traffic demands. By moving beyond the one-size-fits-all approach of Round-Robin allocation, we demonstrate how intelligent slot distribution can improve network performance, especially for multi-hop applications. Our implementation utilizes the Optimized Link State Routing (OLSR) protocol as the underlying routing mechanism, providing proactive path determination between source and destination nodes. The comparative analysis reveals that by adapting slot allocation to traffic patterns and node responsibilities, we can significantly improve network performance.

Open NetSim and Select **Examples** ▸ **TDMA Radio Networks** ▸ **DTDMA** ▸ **Optimized slot allocation for load balancing in dynamic TDMA based MANETs** then click on the tile in the middle panel to load the example as shown.

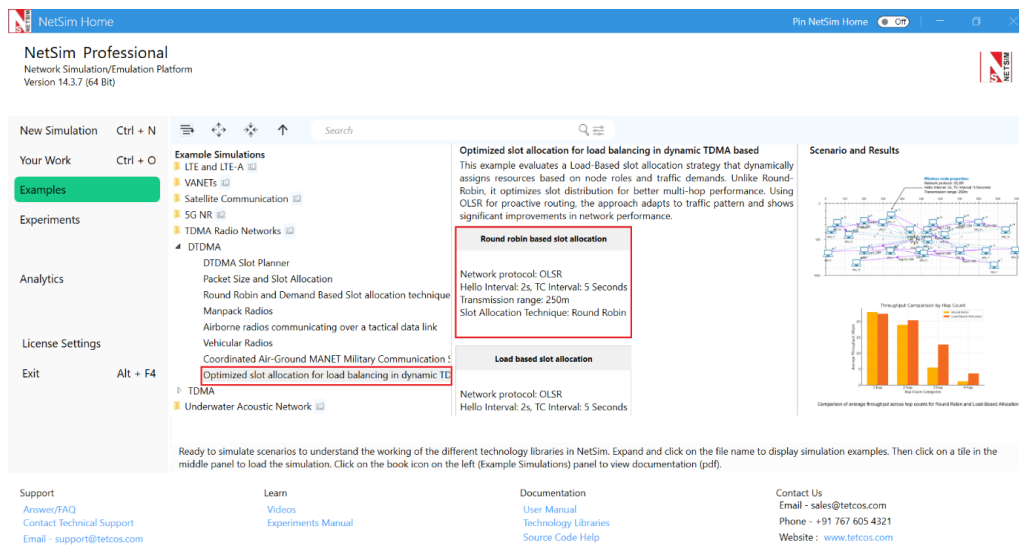


**Figure 4-64:** List of scenarios for the example of Optimized slot allocation for load balancing in dynamic TDMA based MANETs Scenario Overview.

**Table 4-30:** Network Configuration Parameters

| Parameter                 | Value                                                 |
|---------------------------|-------------------------------------------------------|
| Environment size          | 1000m×1000m                                           |
| Mobility Model            | No-Mobility                                           |
| Routing protocol          | OLSR                                                  |
| Transmission range        | 250m                                                  |
| Slot Allocation Technique | Round-Robin-Allocation and Load-Based Slot Allocation |
| OLSR Parameters           | Hello Interval: 2 seconds, TC Interval: 5 Seconds     |

## Scenario Overview

**Network Topology** The network consists of 24 wireless nodes, with multiple applications generating traffic across various hop counts. The topology is designed to highlight the challenges of slot allocation in multi-hop scenarios.

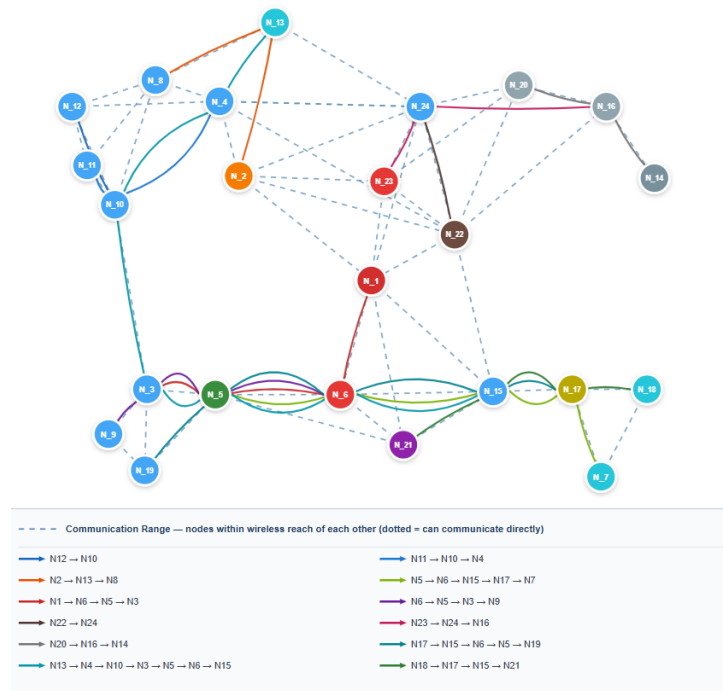


**Figure 4-65:** Illustration of the 24-node wireless multi-hop network where nodes engaged in active transmissions are highlighted. The colored lines represent traffic flows, while the dotted lines depict transmission ranges within the Dynamic TDMA system

## Network Settings

- The simulation environment is configured with a 1000m × 1000m grid before device placement
- In the wireless nodes DTDMA protocol is set in Interface.1 (Wireless) datalink layer we can change slot allocation techniques such as round robin for case-1 and as file based for case-2.

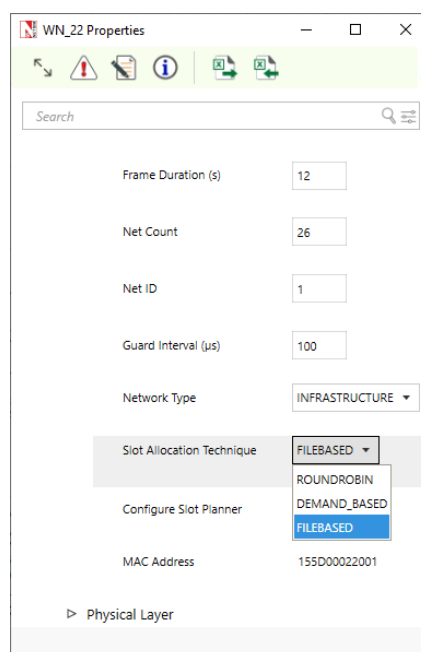


**Figure 4-66:** Slot Allocation Technique Datalink layer properties window

- Application start time is set 15 seconds for the applications

- Enable the Plots, packet trace options and run the simulation for 50 sec.

## Results: Round Robin slot Allocation

The Round-Robin allocation implements:

- Equal slot distribution among all nodes
- Sequential slot assignment
- No consideration of node roles or traffic patterns

The results of RR slot allocation are shown in the table below.

**Table 4-31:** Route taken, hop count and throughput of different applications with RR slot allocation

| Application Name | Route taken             | Hop Count | Throughput (Kbps) |
|------------------|-------------------------|-----------|-------------------|
| App1 CBR         | N12>N10                 | 1         | 34.30             |
| App2 CBR         | N11>N10>N4              | 2         | 17.51             |
| App3 CBR         | N2>N13>N8               | 2         | 10.76             |
| App4 CBR         | N5>N6>N15>N17>N7        | 4         | 1.32              |
| App5 CBR         | N1>N6>N5>N3             | 3         | 2.74              |
| App6 CBR         | N6>N5>N3>N9             | 3         | 4.87              |
| App7 CBR         | N22>N24                 | 1         | 25.12             |
| App8 CBR         | N23>N24>N16             | 2         | 24.91             |
| App9 CBR         | N20>N16>N14             | 2         | 24.00             |
| App10 CBR        | N17>N15>N6>N5>N19       | 4         | 1.27              |
| App11 CBR        | N13>N4>N10>N3>N5>N6>N15 | 6         | 0.96              |
| App12 CBR        | N18>N17>N15>N21         | 3         | 9.54              |

## Throughput and Hop Count Analysis

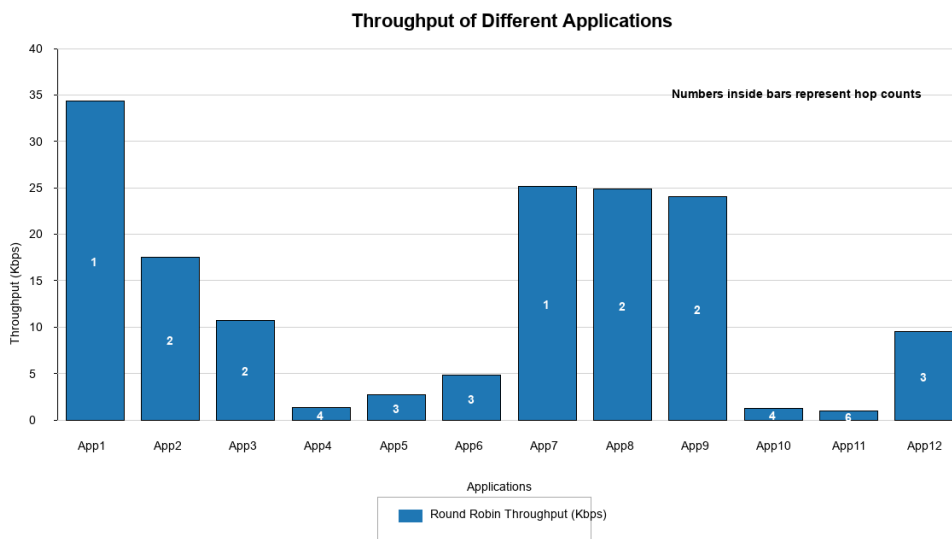


**Figure 4-67:** Throughput comparison of different applications with RR slot allocation. We observe applications with higher hop count get a much lower throughput.

## Challenges with round robin slot allocation

- Inefficient slot distribution

- Equal slot allocation does not consider node roles, leading to inefficient use of resources.
- Single-hop and destination nodes receive the same slots as relay nodes, limiting opportunities for high-hop applications.
- Relay node bottlenecks
  - Critical relay nodes receive insufficient slots, leading to congestion.
  - Multiple applications compete for limited relay resources, resulting in performance degradation.
- Throughput decline with increasing hop count
  - High-hop applications suffer from lower throughput, as relay nodes do not get priority.
  - Unfair slot distribution limits long-path applications, reducing network efficiency.

## Load-based slot allocation

To overcome these challenges, we devise a Load-Based Slot Allocation mechanism which categorizes nodes based on their roles and traffic demand

## Node Categorization

**Table 4-32:** *Node classification in Load-Based slot allocation*

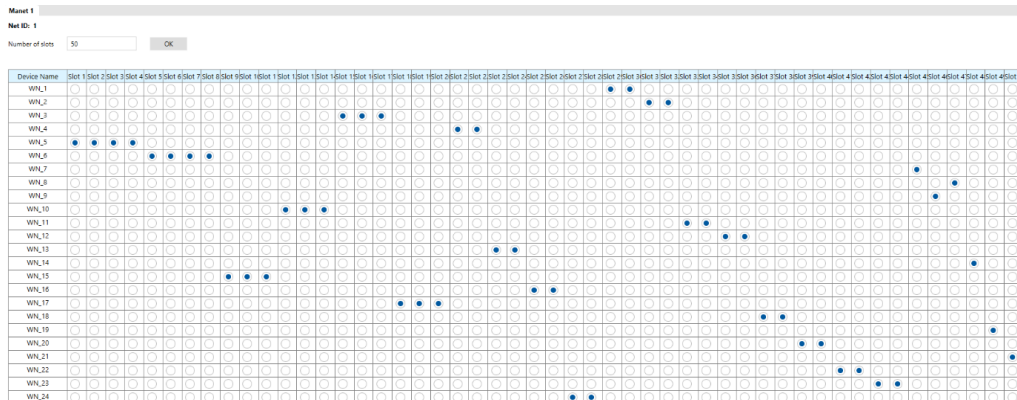
| Node Category                  |  | Description                                                     |
|--------------------------------|--|-----------------------------------------------------------------|
| Critical Relays (3 or 4 slots) |  | Handles 3 or more application flows                             |
| Regular Nodes (2 slots)        |  | Handles 1 or 2 application flows                                |
| Destination Nodes (1 slots)    |  | Only receives traffic (no relay function) Zero outgoing traffic |

## Slot allocation

**Table 4-33:** Slot Allocation with load-based scheduling. The total number of slots in one cycle is 50.

| Node | Role             | Applications involved          | Slots Allocated |
|------|------------------|--------------------------------|-----------------|
| N5   | Critical Relay   | App4, App5, App6, App10, App11 | 1, 2, 3, 4      |
| N6   | Critical Relay   | App4, App5, App6, App10, App11 | 5, 6, 7, 8      |
| N15  | Critical Relay   | App4, App10, App11, App12      | 9, 10, 11       |
| N10  | Critical Relay   | App1, App2, App11              | 12, 13, 14      |
| N3   | Regular Node     | App5, App6, App11              | 15, 16, 17      |
| N17  | Regular Node     | App4, App10, App12             | 18, 19, 20      |
| N4   | Regular Node     | App2, App11                    | 21, 22          |
| N13  | Regular Node     | App3, App11                    | 23, 24          |
| N16  | Regular Node     | App8, App9                     | 25, 26          |
| N24  | Regular Node     | App7, App8                     | 27, 28          |
| N1   | Regular Node     | App5                           | 29, 30          |
| N2   | Regular Node     | App3                           | 31, 32          |
| N11  | Regular Node     | App2                           | 33, 34          |
| N12  | Regular Node     | App1                           | 35, 36          |
| N18  | Regular Node     | App12                          | 37, 38          |
| N20  | Regular Node     | App9                           | 39, 40          |
| N22  | Regular Node     | App7                           | 41, 42          |
| N23  | Regular Node     | App8                           | 43, 44          |
| N7   | Destination Node | App4                           | 45              |
| N9   | Destination Node | App6                           | 46              |
| N8   | Destination Node | App3                           | 47              |
| N14  | Destination Node | App9                           | 48              |
| N19  | Destination Node | App10                          | 49              |
| N21  | Destination Node | App12                          | 50              |

## NetSim Slot Planner

**Figure 4-68:** NetSim GUI - Slot allocation matrix for the 24-node network with load-based slot allocation

## Results and Discussion

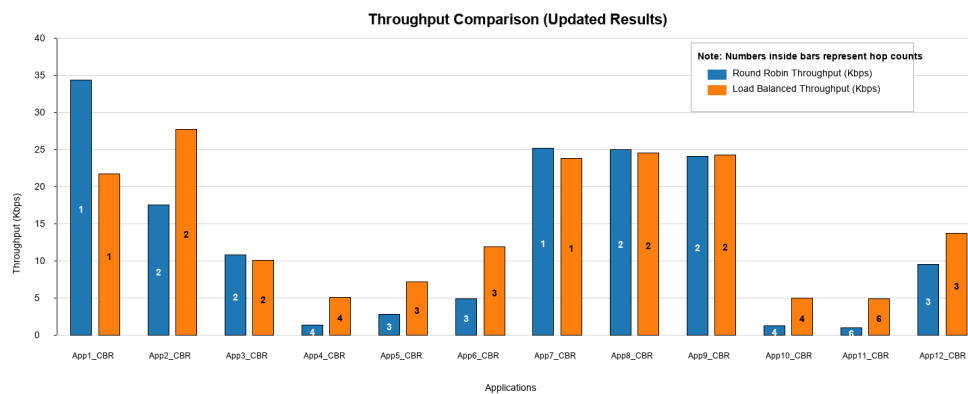
The throughput comparison between Round Robin and Slot-Based allocation reveals significant improvements in network performance. In Round Robin allocation, each of the 24 nodes received exactly one slot. However, in the Load-Based approach, we allocated a total of 50 slots distributed among the same 24 nodes based on their roles and traffic demands.

**Table 4-34:** Application wise throughput comparison between round robin and load-based slot allocation

| Application Name | Route taken             | Hop-Count | Round robin Slot allocation. Throughput (Kbps) | Load Balanced slot allocation. Throughput (Kbps) | Improvement (%) |
|------------------|-------------------------|-----------|------------------------------------------------|--------------------------------------------------|-----------------|
| App1.CBR         | N12>N10                 | 1         | 34.30                                          | 21.72                                            | -36.69          |
| App2.CBR         | N11>N10>N4              | 2         | 17.51                                          | 27.65                                            | 57.97           |
| App3.CBR         | N2>N13>N8               | 2         | 10.76                                          | 10.05                                            | -6.60           |
| App4.CBR         | N5>N6>N15>N17>N7        | 4         | 1.32                                           | 5.02                                             | 280.77          |
| App5.CBR         | N1>N6>N5>N3             | 3         | 2.74                                           | 7.15                                             | 161.11          |
| App6.CBR         | N6>N5>N3>N9             | 3         | 4.87                                           | 11.82                                            | 142.71          |
| App7.CBR         | N22>N24                 | 1         | 25.12                                          | 23.80                                            | -5.25           |
| App8.CBR         | N23>N24>N16             | 2         | 24.91                                          | 24.46                                            | -1.83           |
| App9.CBR         | N20>N16>N14             | 2         | 24.00                                          | 24.20                                            | 0.85            |
| App10.CBR        | N17>N15>N6>N5>N19       | 4         | 1.27                                           | 4.97                                             | 292.00          |
| App11.CBR        | N13>N4>N10>N3>N5>N6>N15 | 6         | 0.96                                           | 4.87                                             | 405.26          |
| App12.CBR        | N18>N17>N15>N21         | 3         | 9.54                                           | 13.70                                            | 43.62           |

**Table 4-35:** Average Throughput Comparison for Different Hop Counts.

| Application Types  | Round Robin Slot Allocation (Avg.) | Load Balanced Slot Allocation (Avg.) | Change  |
|--------------------|------------------------------------|--------------------------------------|---------|
| 1-hop Applications | 29.71 Kbps                         | 22.76 Kbps                           | -23.40% |
| 2-hop Applications | 19.29 Kbps                         | 21.59 Kbps                           | 11.90%  |
| 3-hop Applications | 5.72 Kbps                          | 10.89 Kbps                           | 90.53%  |
| 4-hop Applications | 1.29 Kbps                          | 5.00 Kbps                            | 286.27% |
| 6-hop Applications | 0.96 Kbps                          | 4.87 Kbps                            | 405.26% |

**Figure 4-69:** Throughput Comparison Between Round Robin and Slot-Based Allocation for Different Applications

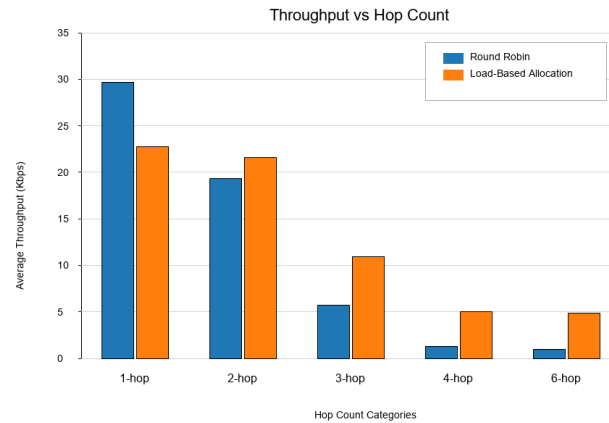


**Figure 4-70:** Comparison of average throughput across hop counts for Round Robin and Load-Based Allocation

Traditional Round-Robin slot allocation, while simple to implement, suffers from performance limitations in multi-hop networks. It allocates resources uniformly without considering node roles or traffic patterns, which leads to bottlenecks at relay nodes and reduced throughput for multi-hop applications. This issue becomes more pronounced as the hop count increases. From the updated results, the average throughput drops from 29.71 Kbps for 1-hop applications to 1.29 Kbps for 4-hop applications and 0.96 Kbps for 6-hop applications, showing the inefficiency of uniform slot distribution in multi-hop scenarios.

The proposed Load-Based slot allocation mechanism addresses these limitations by distributing slots based on node roles and traffic demand. By allocating more slots to critical relay nodes and fewer slots to destination nodes, the scheme improves data forwarding across multiple hops. The results show throughput improvements for higher hop counts. The average throughput of 3-hop applications increases from 5.72 Kbps to 10.89 Kbps, 4-hop applications increase from 1.29 Kbps to 5.00 Kbps, and 6-hop applications increase from 0.96 Kbps to 4.87 Kbps.

These improvements come with a reduction in 1-hop average throughput, from 29.71 Kbps to 22.76 Kbps, because slots are shifted toward relay-heavy paths. Overall, load-based slot allocation improves multi-hop throughput and increases total throughput from 157.30 Kbps to 179.43 Kbps, making it better suited for networks where multi-hop communication is critical.

#### 4.1.9 TDMA Latency and Queueing Lengths for Random and Fixed Traffic Patterns

This experiment examines the end-to-end latency and queueing behavior in a TDMA-based multi-node network under two distinct traffic patterns: Poisson (random) arrivals and deterministic (fixed) arrivals. We derive analytical expressions for average delay and queue length and compare against NetSim simulations. The slot allocation is round robin. The study evaluates scenarios with 2 to 10 nodes, analyzing how system load, slot duration, and arrival patterns influence performance.

For Poisson traffic, randomness introduces queueing delays even under stable loads. In contrast, deterministic arrivals (representing periodic traffic such as 1 packet every second) exhibit zero queueing when inter-arrival times align with TDMA slots. Results demonstrate strong agreement between theory and simulation, offering insights for designing efficient TDMA systems where latency is critical.

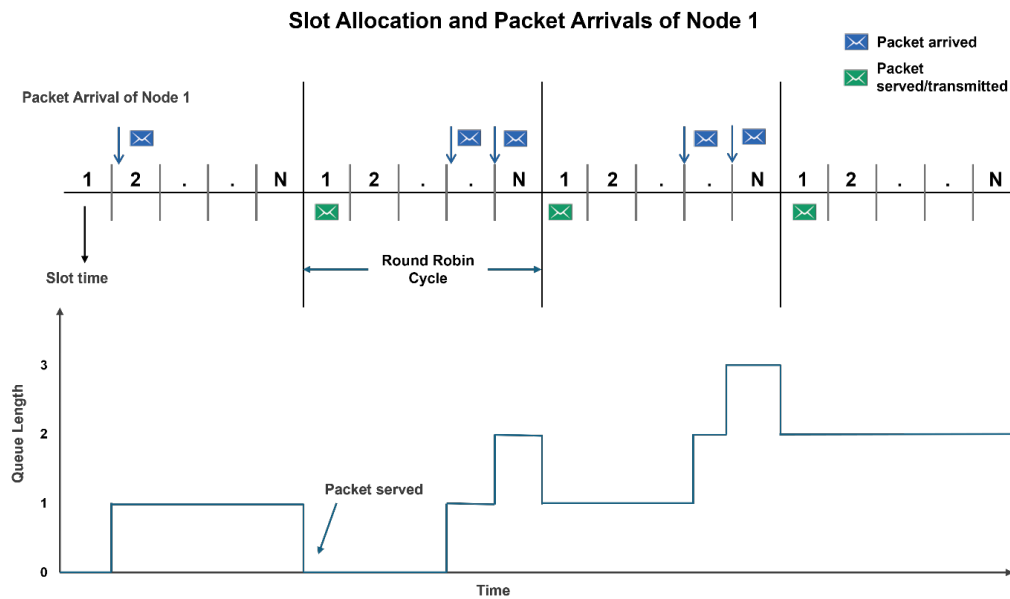


**Figure 4-71:** Illustration of variation in the queue length of a node depending on arrivals and service. Observe that a node can only serve a packet when its turn arrives in the TDMA (round robin) schedule. However, packet arrivals are random. This leads to queueing, as shown in the bottom panel.

## Network Setup

Create a scenario with N nodes as shown below. The number of nodes N is varied in each sample as

- sample 1: 2 nodes,
- sample 2: 3 nodes,
- sample 3: 4 nodes,
- ...
- sample 9: 10 nodes.

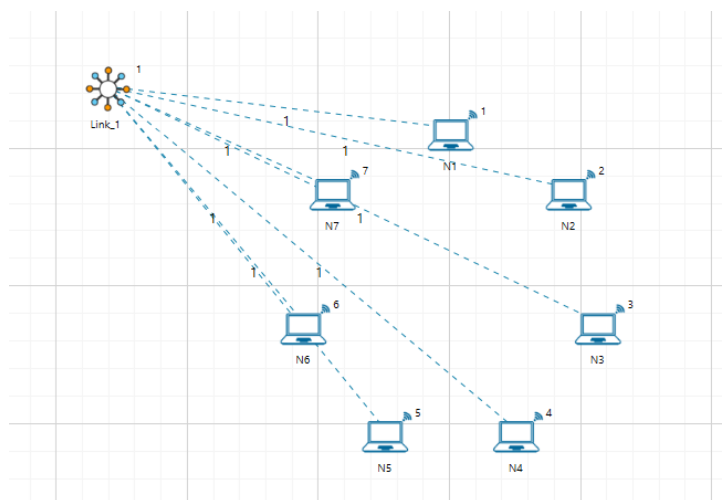


**Figure 4-72:** Network setup for Latency analysis of DTDMA

## Network settings

The experiment evaluates TDMA performance under two traffic regimes—exponential (random) arrivals and deterministic (fixed) arrivals—across networks of 2 to 10 nodes. Then we consider two cases: one application and  $N$  applications (one per node). The queuing delay for a node depends only on its own arrival rate ( $\lambda$ ) and slot cycle length ( $N \cdot T_s$ ) and not on other nodes' traffic. The reason: since slots are pre-allocated via round-robin, the queue dynamics at one node are unaffected by others.

### Part A: Poisson arrivals

- Consider  $N$  nodes placed in the network. The distance between neighboring nodes is set to 5000m to ensure a fixed propagation delay.
- The following properties are configured for each node

**Table 4-36:** *Properties window for wireless node*

| Link Layer Properties     |             |
|---------------------------|-------------|
| Slot Duration             | 20 ms       |
| Guard interval            | 1 $\mu$ s   |
| Slot Allocation Technique | Round Robin |
| Physical Layer Properties |             |
| Bandwidth                 | 100 KHz     |
| Data symbol rate          | 100 kBd     |
| Tx Power                  | 20 W        |
| Modulation Technique      | QPSK        |
| Coding Rate               | 1/2         |
| Mobility Settings         |             |
| Mobility Model            | No Mobility |

- Data rate is  $\text{SymbolRate} \times \text{ModulationOrder} \times \text{CodingRate} = 100 \text{ Kbps}$
- The slot capacity in Bytes is  $\frac{\text{DataRate} \times \text{SlotDuration}}{8} = \frac{100 \cdot 10^3 \times 20 \cdot 10^{-3}}{8} = 250 \text{ B}$
- Case A: One traffic flow: Application is configured N1 – N2
- Case B:  $N$  traffic flows: Applications are configured such that communication occurs between N1 - N2, N2 - N3, ..., N(n-1) - N(n) where  $n$  is the number of nodes in the sample.

**Table 4-37:** *Application properties*

| Application (Traffic Flow) Properties |                                                                                                   |
|---------------------------------------|---------------------------------------------------------------------------------------------------|
| Packet Size (Application Layer)       | 222 B (This becomes 250B on addition of overheads of MAC and PHY which matches the slot capacity) |
| IAT (Exponential)                     | 500,000 $\mu$ s (or 2 packets per second)                                                         |

Static routing is configured between the nodes to avoid the ad hoc routing control packets.

Run the simulation for 5000s.

### Latency Analysis

Assumptions

- Round robin TDMA slot allocation: Each node serves packets once every  $N$  slots i.e., the cycle length  $N \times T_s$  where  $T_s$  is the slot time, and  $N$  is the number of nodes
- Poisson Arrivals: Packets arrive at node N1 with rate  $\lambda$  pkts/second. We assume  $\lambda < \frac{1}{(N \times T_s)}$  for stability.
- Service Time: Each packet takes  $T_s$  time to transmit once its slot begins i.e., one packet is transmitted in a slot.

Obtaining the expression for the total delay

- Residual Waiting Time: A packet can arrive uniformly during the  $N \times T_s$  length cycle. On average, it waits  $\frac{(N \cdot T_s)}{2}$  for the next node-specific slot.
- Queueing Delay: Let  $L_q$  be the average number of packets already queued. Each contributes  $N \cdot T_s$  delay (due to the periodic services).
- Combine residual waiting time, queueing delay, and service time to compute the average delay  $W$ :

$$W = \underbrace{\frac{(N \cdot T_s)}{2}}_{\text{Residual waiting}} + \underbrace{L_q \cdot N \cdot T_s}_{\text{Queueing}} + \underbrace{T_s}_{\text{Service}} \quad (22)$$

- Apply Little's Law: The average queue length  $L_q = \lambda \times W_q$ , where  $W_q = W - T_s$ , the queueing delay excluding service time.
- Substituting  $L_q$ :

$$W = \frac{(N \times T_s)}{2} + \lambda \cdot (W - T_s) \cdot N \cdot T_s + T_s \quad (23)$$

- Solving for  $W$  we get:

$$W = \frac{T_s (N + 2 - 2\lambda N T_s)}{2(1 - \lambda N T_s)} \quad (24)$$

- To this we add propagation delay and the mean end-to-end delay for a node is

$$W_{total} = \frac{T_s (N + 2 - 2\lambda N T_s)}{2(1 - \lambda N T_s)} + \frac{D}{c} \quad (25)$$

Where  $D$  is the distance between the nodes and  $c$  is the speed of light.

## Theoretical Calculation

- To compute the Total average delay  $W_{total}$ , using

$$W_{total} = \frac{T_s (N + 2 - 2\lambda N T_s)}{2(1 - \lambda N T_s)} + \frac{D}{c}$$

Where  $T_s = 20$  ms (or 0.02s) is the slot duration,

$\lambda = 2$  packets/sec,

$N$  is the number of nodes in the TDMA cycle

Propagation Delay:

The propagation delay is

$$\text{Propagation delay} = \frac{D}{c} = \frac{5000}{3 \times 10^8} = 0.01667 \text{ ms}$$

Mean end-to-end delay:

The mean end-to-end delay is

$$W = \frac{T_s (N + 2 - 2\lambda NT_s)}{2(1 - \lambda NT_s)}$$

$$W = \frac{0.02 (2 + 2 - (2 \times 2 \times 2 \times 0.02))}{2 (1 - 2 \times 2 \times 0.02)} = 0.04174 \text{ s} = 41.74 \text{ ms}$$

Total Delay Calculation:

Adding end-to-end delay and propagation delay

$$W_{total} = 41.74 \text{ ms} + 0.01667 \text{ ms} = 41.7567 \text{ ms}$$

## Simulation Results

Case A (with 1 application):

In the case with 2 nodes and 1 - application, we see the following results from the simulation

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

| App. ID | App. Name   | Src. ID | Dest. ID | Gen. Rate | Thput Mbps ▼ | Delay ms ▼  |
|---------|-------------|---------|----------|-----------|--------------|-------------|
| 1       | App1_CUSTOM | 1       | 2        | 0.00355   | 0.003536     | 41.58031811 |

**Figure 4-73:** Application metrics from the result dashboard

Transmission time + Propagation delay:

Calculate the transmission time including propagation delay using the packet trace and the following formula.

$$\text{Transmission time} + \text{Propagation delay} = \text{PHY END TIME} - \text{PHY LAYER START TIME}$$

|    | L                          | M                          | N                        | O                      | P                            | Q          | R                        |     |
|----|----------------------------|----------------------------|--------------------------|------------------------|------------------------------|------------|--------------------------|-----|
|    | MAC LAYER ARRIVAL TIME(μs) | PHY LAYER ARRIVAL TIME(μs) | PHY LAYER START TIME(μs) | PHY LAYER END TIME(μs) | Transmission Time + Prop del | Column2    | APP LAYER PAYLOAD(Bytes) | TRX |
| 1  | 0                          | 20000.0                    | 20000.0                  | 20000.0                | 20016.678                    | 200010     |                          | 222 |
| 2  | 660005.915                 | 800040                     | 800040                   | 820005.678             | 20016.678                    | 140034.085 |                          | 222 |
| 3  | 804748.713                 | 1000050                    | 1000050                  | 1020066.678            | 20016.678                    | 195301.287 |                          | 222 |
| 4  | 1255679.81                 | 1400070                    | 1400070                  | 1420086.678            | 20016.678                    | 144390.19  |                          | 222 |
| 5  | 1720528.696                | 1800090                    | 1800090                  | 1820106.678            | 20016.678                    | 79561.304  |                          | 222 |
| 6  | 2062765.564                | 2200110                    | 2200110                  | 2220126.678            | 20016.678                    | 137344.436 |                          | 222 |
| 7  | 2145903.263                | 2400120                    | 2400120                  | 2420136.678            | 20016.678                    | 254216.737 |                          | 222 |
| 8  | 2727153.438                | 2800140                    | 2800140                  | 2820156.678            | 20016.678                    | 72096.561  |                          | 222 |
| 9  | 2783588.036                | 3000150                    | 3000150                  | 3020166.678            | 20016.678                    | 216561.964 |                          | 222 |
| 10 | 3023026.244                | 3200160                    | 3200160                  | 3220176.678            | 20016.678                    | 177133.756 |                          | 222 |
| 11 | 3532568.153                | 3600180                    | 3600180                  | 3620196.678            | 20016.678                    | 67611.847  |                          | 222 |
| 12 | 3841303.126                | 4000200                    | 4000200                  | 4020216.678            | 20016.678                    | 158896.874 |                          | 222 |
| 13 | 3904797.366                | 4200210                    | 4200210                  | 4220226.678            | 20016.678                    | 295412.634 |                          | 222 |
| 14 | 4072016.622                | 4400220                    | 4400220                  | 4420236.678            | 20016.678                    | 328203.378 |                          | 222 |
| 15 | 4737247.359                | 4800240                    | 4800240                  | 4820256.678            | 20016.678                    | 62992.641  |                          | 222 |
| 16 | 4772438.222                | 5000250                    | 5000250                  | 5020266.678            | 20016.678                    | 227811.778 |                          | 222 |
| 17 | 5718732.973                | 5800290                    | 5800290                  | 5820306.678            | 20016.678                    | 81557.027  |                          | 222 |
| 18 | 5924266.829                | 6000300                    | 6000300                  | 6020316.678            | 20016.678                    | 76039.171  |                          | 222 |
| 19 | 5968146.245                | 6200310                    | 6200310                  | 6220326.678            | 20016.678                    | 232163.755 |                          | 222 |
| 20 | 6188929.641                | 6400320                    | 6400320                  | 6420336.678            | 20016.678                    | 211390.359 |                          | 222 |
| 21 | 808696.912                 | 8200410                    | 8200410                  | 8220426.678            | 20016.678                    | 113713.088 |                          | 222 |
| 22 | 8609274.575                | 8800440                    | 8800440                  | 8820456.678            | 20016.678                    | 191165.425 |                          | 222 |
| 23 | 8707796.224                | 9000450                    | 9000450                  | 9020466.678            | 20016.678                    | 290558.776 |                          | 222 |
| 24 | 9201065.167                | 9400470                    | 9400470                  | 9420486.678            | 20016.678                    | 199404.833 |                          | 222 |
| 25 | 9216149.56                 | 9600480                    | 9600480                  | 9620496.678            | 20016.678                    | 384330.44  |                          | 222 |
| 26 | 10593144.89                | 10600530                   | 10600530                 | 10620546.68            | 20016.678                    | 7385.106   |                          | 222 |
| 27 | 10805071.63                | 11000550                   | 11000550                 | 11020566.68            | 20016.678                    | 195478.371 |                          | 222 |
| 28 | 10842245.12                | 11200560                   | 11200560                 | 11220576.68            | 20016.678                    | 358314.863 |                          | 222 |
| 29 | 11274358.83                | 11400570                   | 11400570                 | 11420586.68            | 20016.678                    | 126211.171 |                          | 222 |
| 30 | 11335308.93                | 11600580                   | 11600580                 | 11620596.68            | 20016.678                    | 265271.069 |                          | 222 |
| 31 | 12470190.57                | 12500629                   | 12500629                 | 12600645.68            | 20016.678                    | 110438.43  |                          | 222 |

**Figure 4-74:** Transmission Time and Propagation delay analysis using packet trace

For only one Application configured (N1 – N2) transmission time and propagation delay:

$$T_{tx} + T_{prop} = 20016.678 \mu s = 20.016678 \text{ ms}$$

Queueing Delay calculation

To calculate queueing delay, we use

Queueing Delay = PHY LAYER ARRIVAL TIME – NETWORK LAYER ARRIVAL TIME

|    | K           | L                         | M                          | N                          | O                        | P                      | Q                  |
|----|-------------|---------------------------|----------------------------|----------------------------|--------------------------|------------------------|--------------------|
|    | TIME(μs)    | NW LAYER ARRIVAL TIME(μs) | MAC LAYER ARRIVAL TIME(μs) | PHY LAYER ARRIVAL TIME(μs) | PHY LAYER START TIME(μs) | PHY LAYER END TIME(μs) | QUEUEING DELAY(μs) |
| 1  | 0           | 0                         | 0                          | 0                          | 0                        | 0                      | 0                  |
| 2  | 660005.915  | 660005.915                | 660005.915                 | 680034                     | 680034                   | 700005.678             | 20028.085          |
| 3  | 804748.713  | 804748.713                | 804748.713                 | 840042                     | 840042                   | 860008.678             | 55291.287          |
| 4  | 1255679.81  | 1255679.81                | 1255679.81                 | 1300064                    | 1300064                  | 1300090.678            | 24348.19           |
| 5  | 1720528.696 | 1720528.696               | 1720528.696                | 1760088                    | 1760088                  | 1780184.678            | 59558.264          |
| 6  | 2062765.564 | 2062765.564               | 2062765.564                | 2100104                    | 2100104                  | 2100130.678            | 17338.436          |
| 7  | 2145903.263 | 2145903.263               | 2145903.263                | 2160108                    | 2160108                  | 2180124.678            | 14204.737          |
| 8  | 2727153.438 | 2727153.438               | 2727153.438                | 2760138                    | 2760138                  | 2780134.678            | 52094.561          |
| 9  | 2783588.036 | 2783588.036               | 2783588.036                | 2800140                    | 2800140                  | 2820156.678            | 36051.964          |
| 10 | 3023026.244 | 3023026.244               | 3023026.244                | 3040152                    | 3040152                  | 3060184.678            | 17315.799          |
| 11 | 3532568.153 | 3532568.153               | 3532568.153                | 3560176                    | 3560176                  | 3580184.678            | 27698.847          |
| 12 | 3841303.126 | 3841303.126               | 3841303.126                | 3880184                    | 3880184                  | 3900210.678            | 36030.874          |
| 13 | 3904797.366 | 3904797.366               | 3904797.366                | 3920196                    | 3920196                  | 3940212.678            | 35398.634          |
| 14 | 4072016.622 | 4072016.622               | 4072016.622                | 4080204                    | 4080204                  | 4100210.678            | 8167.376           |
| 15 | 4737247.359 | 4737247.359               | 4737247.359                | 4760238                    | 4760238                  | 4780254.678            | 23996.641          |
| 16 | 4772438.222 | 4772438.222               | 4772438.222                | 4800240                    | 4800240                  | 4820256.678            | 27801.779          |
| 17 | 5718732.973 | 5718732.973               | 5718732.973                | 5720286                    | 5720286                  | 5740302.678            | 18542.027          |
| 18 | 5924266.829 | 5924266.829               | 5924266.829                | 5960288                    | 5960288                  | 5980314.678            | 36037.171          |
| 19 | 5968146.245 | 5968146.245               | 5968146.245                | 6000300                    | 6000300                  | 6020316.678            | 32163.794          |
| 20 | 6188929.641 | 6188929.641               | 6188929.641                | 6200310                    | 6200310                  | 6220326.678            | 11380.359          |
| 21 | 808696.912  | 808696.912                | 808696.912                 | 8120406                    | 8120406                  | 8140422.678            | 55798.585          |
| 22 | 8609274.575 | 8609274.575               | 8609274.575                | 8640432                    | 8640432                  | 8660448.678            | 51157.425          |
| 23 | 8707796.224 | 8707796.224               | 8707796.224                | 8720436                    | 8720436                  | 8740452.678            | 12643.776          |
| 24 | 9201065.167 | 9201065.167               | 9201065.167                | 9240462                    | 9240462                  | 9260478.678            | 50096.833          |
| 25 | 9216149.56  | 9216149.56                | 9216149.56                 | 9280464                    | 9280464                  | 9300480.678            | 64334.44           |
| 26 | 10593144.89 | 10593144.89               | 10593144.89                | 10600530                   | 10600530                 | 10620546.68            | 7385.106           |
| 27 | 10805071.63 | 10805071.63               | 10805071.63                | 10804542                   | 10804542                 | 10820558.68            | 56479.971          |
| 28 | 10842245.12 | 10842245.12               | 10842245.12                | 10880544                   | 10880544                 | 10900560.68            | 36298.893          |
| 29 | 11274358.83 | 11274358.83               | 11274358.83                | 11280564                   | 11280564                 | 11300580.68            | 6206.174           |
| 30 | 11335308.93 | 11335308.93               | 11335308.93                | 11380568                   | 11380568                 | 11400586.68            | 20205.065          |
| 31 | 12470190.57 | 12470190.57               | 12470190.57                | 12500629                   | 12500629                 | 12520641.68            | 36434.43           |

**Figure 4-75:** Queueing Delay analysis using packet trace

For only one Application configured (N1 – N2) queueing delay:

$$W_q = 21.563 \text{ ms}$$

The slot time is 20 ms and guard interval is 1 ms which is approximately equal to the queueing delay  $21.56 \text{ ms} \approx 21 \text{ ms}$

The total delay or latency is the sum of transmission time, propagation delay, and queueing delay.

$$W_{total} = 20.0167 + 21.563 = 41.5803 \text{ ms}$$

Case B (with n applications):

We consider a second case (with n- applications) where we have two applications (traffic flows). They are configured from (N1 – N2) and (N2 – N1).

Open packet trace filter SOURCE\_ID to “NODE-1” then calculate the Queueing Delay we get:

$$W_q = 21.563 \text{ ms}$$

Adding all transmission time, propagation delay and Queueing delay for total delay or latency

$$W_{total} = 20.0167 + 21.563 = 41.5803 \text{ ms}$$

Similarly, we obtain results for all samples as follows

- sample 1: 2 nodes, 1 Application and 2 Applications
- sample 2: 3 nodes, 1 Application and 3 Applications
- sample 3: 4 nodes, 1 Application and 4 Applications
- ...
- sample 9: 10 nodes. 1 Application and 10 Applications

## Results

**Table 4-38:** Queueing delay analysis with increasing nodes

| Node count (N) | Queueing Delay for 1 App |                 | Queueing delay for N Apps |                 |
|----------------|--------------------------|-----------------|---------------------------|-----------------|
|                | Theoretical (ms)         | Simulation (ms) | Theoretical (ms)          | Simulation (ms) |
| 2              | 41.756                   | 41.580          | 41.756                    | 41.580          |
| 3              | 54.108                   | 53.961          | 54.108                    | 53.961          |
| 4              | 67.636                   | 67.628          | 67.636                    | 67.628          |
| 5              | 82.517                   | 82.209          | 82.517                    | 82.209          |
| 6              | 98.964                   | 98.482          | 98.964                    | 98.482          |
| 7              | 117.239                  | 117.247         | 117.239                   | 117.247         |
| 8              | 137.664                  | 136.135         | 137.664                   | 136.135         |
| 9              | 160.642                  | 157.145         | 160.642                   | 157.145         |
| 10             | 186.683                  | 185.213         | 186.683                   | 185.213         |

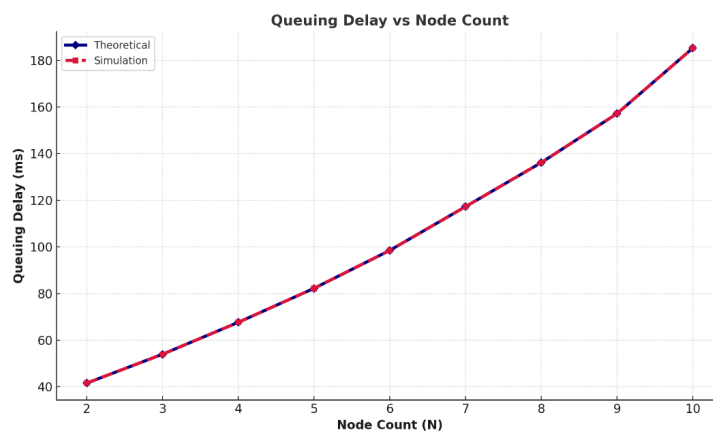


**Figure 4-76:** Queueing Delay vs Node Count

## Queue Length

## Queue Length Analysis

1. From prior analysis, the mean end-to-end delay for a packet is:

$$W = T_s \frac{N + 2 - 2\lambda NT_s}{2(1 - \lambda NT_s)}$$

2. From Little's law, the average queue length (including the packet being served) is  $L = \lambda W$ . Subtracting the utilization  $\rho = \lambda T_s$  (packet in service), the queue length becomes:

$$L_q = L - \rho = \lambda W - \lambda T_s$$

3. Substitute W and simplify:

$$L_q = \lambda \cdot \frac{T_s(N + 2 - 2\lambda NT_s)}{2(1 - \lambda NT_s)} - \lambda T_s$$

After algebraic manipulation, this reduces to:

$$L_q = \frac{\lambda NT_s}{2(1 - \lambda NT_s)} \quad (26)$$

To calculate the average queue length, enable the buffer occupancy log and then run the simulation.

|    | A                   | B         | C           | D            | E                      | F                            | G                      | H                      | I       |
|----|---------------------|-----------|-------------|--------------|------------------------|------------------------------|------------------------|------------------------|---------|
|    | Time (Microseconds) | Device ID | Device Name | Interface ID | Interface Name         | Occupied Buffer Size (Bytes) | Total Buffer Size (MB) | Virtual Interface Name | Remarks |
| 2  | 0                   | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 4  | 450931.0974         | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 6  | 915779.9831         | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 8  | 1258016.851         | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 10 | 1341154.55          | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 12 | 1922404.726         | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 14 | 1978839.322         | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 16 | 2218277.53          | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 18 | 2281771.771         | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 20 | 2448991.027         | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 22 | 3114221.764         | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 24 | 3149412.627         | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 26 | 4095707.378         | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 28 | 4316490.774         | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 30 | 6214258.045         | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 32 | 6707532.989         | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 34 | 6722617.382         | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 36 | 8099612.715         | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 38 | 8531726.426         | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 40 | 8592676.528         | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 42 | 9727558.168         | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 44 | 10436948.02         | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |
| 46 | 11384284.69         | 1         | N1          | 1            | Interface_1 (WIRELESS) | 250                          | inf                    | N/A                    | ENQUEUE |

**Figure 4-77:** Buffer Occupancy log to calculate average queue length

After the simulation, open the Buffer\_Occupancy\_Log file and filter the entries where the device ID is 1 and the remarks field is set to ENQUEUE.

Calculate the average of the occupied buffer size (in bytes) for these entries.

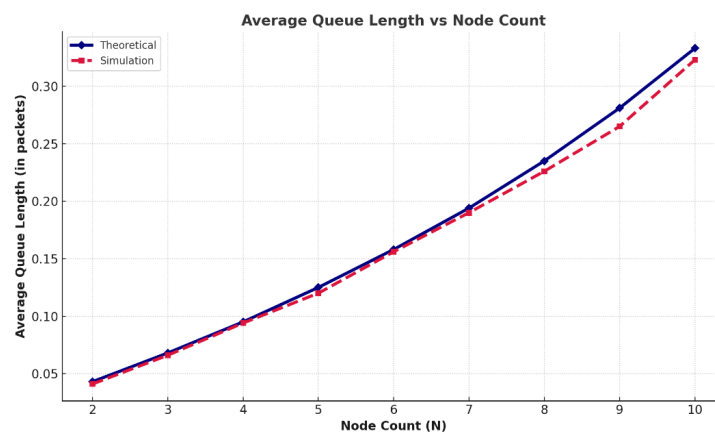
Divide this average by the PHY Layer Payload, then subtract 1 to obtain the average queue length.

$$\begin{aligned} \text{Avg. Queue Length} &= \frac{\text{Avg. Occupied Buffer Size (B)}}{\text{PHY\_LAYER\_PAYLOAD (B)}} - 1 \\ &= \frac{260.02}{250} - 1 = 1.04 - 1 = 0.04 \end{aligned}$$

The average queue length for increasing nodes, with 1 application and n applications, is shown below.

**Table 4-39:** *Queue length analysis with increasing nodes*

| Nodes count, N | Avg length (Theory) | Avg length. (Sim) | Queue 1 app | Avg length. (Sim) | Queue N Apps |
|----------------|---------------------|-------------------|-------------|-------------------|--------------|
| 2              | 0.043               | 0.041             |             | 0.041             |              |
| 3              | 0.068               | 0.066             |             | 0.066             |              |
| 4              | 0.095               | 0.094             |             | 0.094             |              |
| 5              | 0.125               | 0.120             |             | 0.120             |              |
| 6              | 0.158               | 0.156             |             | 0.156             |              |
| 7              | 0.194               | 0.190             |             | 0.190             |              |
| 8              | 0.235               | 0.226             |             | 0.226             |              |
| 9              | 0.281               | 0.265             |             | 0.265             |              |
| 10             | 0.333               | 0.323             |             | 0.323             |              |

**Figure 4-78:** *Average queue length vs Node count*

In NetSim, a packet that arrives at the beginning or during a slot waits for a complete cycle before it is served, Hence the subtraction.

### Part B: Deterministic Arrivals

Network settings

- Consider two nodes placed 5000m apart
- The following properties are configured:

**Table 4-40:** *Device properties and application configuration*

| Application Properties    |                |
|---------------------------|----------------|
| Packet Size               | 222 B          |
| IAT Distribution          | Constant       |
| IAT                       | 333333 $\mu$ s |
| Link Layer Properties     |                |
| Slot Duration             | 20 ms          |
| Guard interval            | 1 $\mu$ s      |
| Slot Allocation Technique | Round Robin    |
| Physical Layer Properties |                |
| Bandwidth                 | 100 KHz        |
| Data symbol rate          | 100 kBd        |
| Tx Power                  | 20 W           |
| Modulation Technique      | QPSK           |
| Coding Rate               | 1/2            |
| Mobility settings         |                |
| Mobility                  | No Mobility    |

- Data rate is set to 100Kbps.
- Applications are configured between N1 and N2 for all the cases (with increasing Nodes).
- Static routing is configured between the nodes to avoid the control packets.
- Run the simulation for 5000s.

## Waiting time

$$W = \underbrace{\frac{NT_s}{2}}_{\text{Residual wait}} + \underbrace{T_s}_{\text{Service Time}} = T_s \left( \frac{N}{2} + 1 \right) \quad (27)$$

where  $N$  is the number of nodes and  $T_s$  is the slot time.

## Results

**Table 4-41:** *Queueing delay analysis with increasing nodes*

| Nodes N | Theoretical (ms) | Simulation (ms) |
|---------|------------------|-----------------|
| 2       | 40               | 40.013          |
| 3       | 50               | 49.966          |
| 4       | 60               | 59.989          |
| 5       | 70               | 69.894          |
| 6       | 80               | 79.947          |
| 7       | 90               | 89.771          |
| 8       | 100              | 99.943          |
| 9       | 110              | 109.689         |
| 10      | 120              | 119.831         |

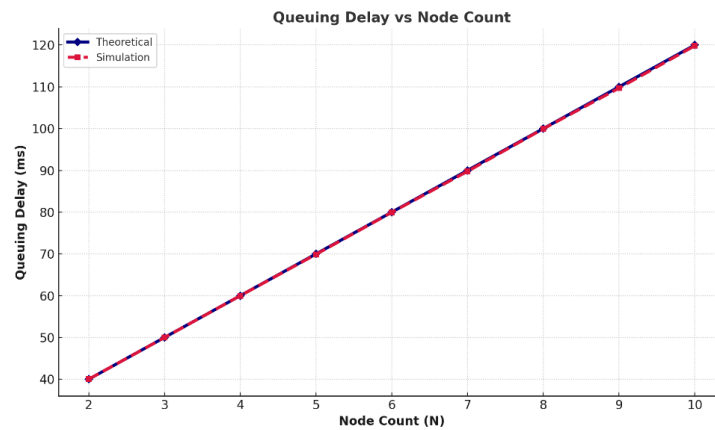


**Figure 4-79:** Queueing Delay vs Node Count

## Conclusion

The simulation results from NetSim closely match the theoretical values derived for both Poisson and deterministic traffic.

## 4.2 TDMA

### 4.2.1 Slot Allocation

Open NetSim and Select **Examples** ▸ **TDMA Radio Networks** ▸ **TDMA** ▸ **TDMA Slot Allocation** then click on the tile in the middle panel to load the example as shown below.

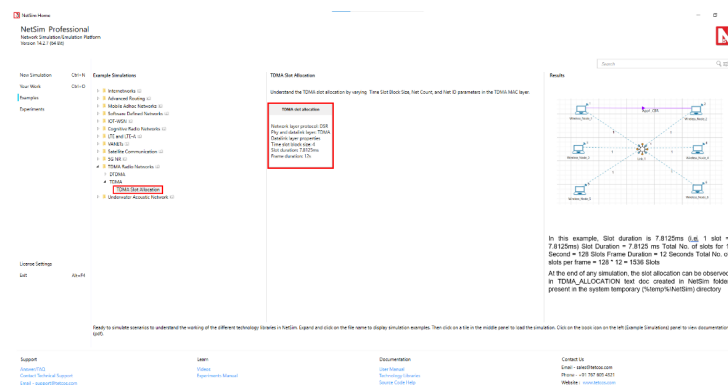


**Figure 4-80:** List of scenarios for the example of TDMA Slot Allocation

The following network diagram illustrates what the NetSim UI displays when you open the example configuration file TDMA-Slot-Allocation as shown below.

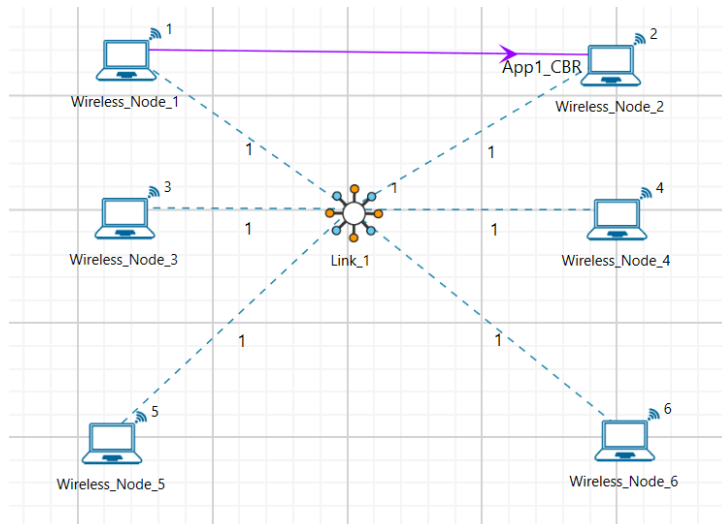


**Figure 4-81:** Network set up for studying the TDMA Slot Allocation

#### Settings done in the Network

1. Grid length: 1000m × 500m from grid setting property panel on the right. This needs to be done before any device is placed on the grid.
2. TDMA protocol is present in wireless node. Set the following properties in wireless nodes. To configure any properties in the nodes, click on the node, expand the property panel on the right side, and change the properties as mentioned in the below steps.

**Table 4-42:** Device properties of wireless nodes

| Device Properties                      |           |
|----------------------------------------|-----------|
| <b>Interface (Wireless) properties</b> |           |
| <b>Datalink layer properties</b>       |           |
| Time Slot Block size                   | 4         |
| Slot duration                          | 7.8125 ms |
| Frame duration                         | 12s       |
| <b>Physical layer properties</b>       |           |
| Antenna height                         | 1         |

3. Configure CBR application from Wireless node 1 to 2 by clicking on set traffic tab on ribbon in the top. Click on the created application, in the property panel on the right, set the Packet Size = 48 B, IAT = 20000  $\mu$ s and start time as 0 sec.
4. Enable Packet trace from Configure reports tab from the ribbon on the top.
5. Run simulation for 20 seconds.

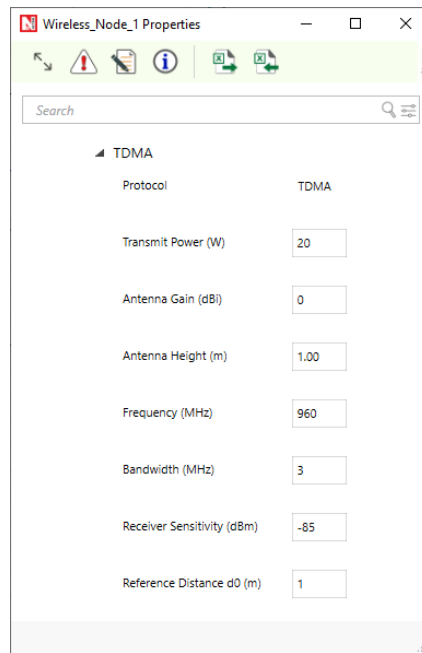


**Figure 4-82:** *TDMA Protocol in Physical layer properties*

**Output** In this example, Slot duration is 7.8125 ms (i.e. 1 slot = 7.8125 ms)

Total No. of slots in 1 second = 128 Slots

Frame Duration = 12 seconds

Total No. of slots per frame =  $128 \times 12 = 1536$  Slots

At the end of any simulation, Open the TDMA slot allocation.csv from the simulation result window. The slot allocation can be observed below.

|    | A      | B        | C             | D           | E       |
|----|--------|----------|---------------|-------------|---------|
|    | NET_ID | FRAME_ID | START_SLOT_ID | END_SLOT_ID | NODE_ID |
| 1  | 1      | 1        | 1             | 4           | 1       |
| 2  | 1      | 1        | 5             | 8           | 2       |
| 3  | 1      | 1        | 9             | 12          | 3       |
| 4  | 1      | 1        | 13            | 16          | 4       |
| 5  | 1      | 1        | 17            | 20          | 5       |
| 6  | 1      | 1        | 21            | 24          | 6       |
| 7  | 1      | 1        | 25            | 28          | 1       |
| 8  | 1      | 1        | 29            | 32          | 2       |
| 9  | 1      | 1        | 33            | 36          | 3       |
| 10 | 1      | 1        | 37            | 40          | 4       |
| 11 | 1      | 1        | 41            | 44          | 5       |
| 12 | 1      | 1        | 45            | 48          | 6       |
| 13 | 1      | 1        | 49            | 52          | 1       |
| 14 | 1      | 1        | 53            | 56          | 2       |
| 15 | 1      | 1        | 57            | 60          | 3       |
| 16 | 1      | 1        | 61            | 64          | 4       |
| 17 | 1      | 1        | 65            | 68          | 5       |
| 18 | 1      | 1        | 69            | 72          | 6       |
| 19 | 1      | 1        | 73            | 76          | 1       |
| 20 | 1      | 1        | 77            | 80          | 2       |
| 21 | 1      | 1        | 81            | 84          | 3       |
| 22 | 1      | 1        | 85            | 88          | 4       |
| 23 | 1      | 1        | 89            | 92          | 5       |
| 24 | 1      | 1        | 93            | 96          | 6       |
| 25 | 1      | 1        |               |             |         |

**Figure 4-83:** *TDMA\_ALLOCATION.CSV*

In the above screenshot columns 1, 2, 3, 4 and 5 specify NET ID, Frame ID, Start Slot ID, End Slot ID and Node ID respectively.

Slots 1-4 are allocated to Node1, Slots 5-8 are allocated to Node2, Slots 9-12 are allocated to Node3, Slots 13-16 are allocated to Node4, Slots 17-20 are allocated to Node5, Slots 21-24 are allocated to Node6.

After this the slot allocation from slot 25 continues from Node1 in the similar way. If all 1536 slots are allocated, then slot allocation for second frame is started as shown below:

|     | A | B | C    | D    | E |
|-----|---|---|------|------|---|
| 376 | 1 | 1 | 1497 | 1500 | 3 |
| 377 | 1 | 1 | 1501 | 1504 | 4 |
| 378 | 1 | 1 | 1505 | 1508 | 5 |
| 379 | 1 | 1 | 1509 | 1512 | 6 |
| 380 | 1 | 1 | 1513 | 1516 | 1 |
| 381 | 1 | 1 | 1517 | 1520 | 2 |
| 382 | 1 | 1 | 1521 | 1524 | 3 |
| 383 | 1 | 1 | 1525 | 1528 | 4 |
| 384 | 1 | 1 | 1529 | 1532 | 5 |
| 385 | 1 | 1 | 1533 | 1536 | 6 |
| 386 | 1 | 2 | 1    | 4    | 1 |
| 387 | 1 | 2 | 5    | 8    | 2 |
| 388 | 1 | 2 | 9    | 12   | 3 |
| 389 | 1 | 2 | 13   | 16   | 4 |
| 390 | 1 | 2 | 17   | 20   | 5 |
| 391 | 1 | 2 | 21   | 24   | 6 |
| 392 | 1 | 2 | 25   | 28   | 1 |
| 393 | 1 | 2 | 29   | 32   | 2 |
| 394 | 1 | 2 | 33   | 36   | 3 |
| 395 | 1 | 2 | 37   | 40   | 4 |
| 396 | 1 | 2 | 41   | 44   | 5 |
| 397 | 1 | 2 | 45   | 48   | 6 |
| 398 | 1 | 2 | 49   | 52   | 1 |
| 399 | 1 | 2 | 53   | 56   | 2 |
| 400 | 1 | 2 | 57   | 60   | 3 |

**Figure 4-84:** *TDMA\_ALLOCATION.CSV*

Analyzing slot allocation using NetSim packet trace

Open Packet trace and filter Control Packet Type/ App Name to APP1 CBR. Insert a new column after PHY Layer End Time column. Then in the new column, take the difference between Phy Layer End Time of the current packet with earlier packet as shown below.

|    | M                          | N                        | O                      | P       |
|----|----------------------------|--------------------------|------------------------|---------|
| 1  | PHY_LAYER_ARRIVAL_TIME[US] | PHY_LAYER_START_TIME[US] | PHY_LAYER_END_TIME[US] | Column1 |
| 38 | 375000                     | 375000                   | 465000                 | 465000  |
| 39 | 562000                     | 562000                   | 592500                 | 187500  |
| 40 | 750000                     | 750000                   | 780000                 | 187500  |
| 41 | 937000                     | 937000                   | 967500                 | 187500  |
| 42 | 1125000                    | 1125000                  | 1155000                | 187500  |
| 43 | 1312000                    | 1312000                  | 1342500                | 187500  |
| 44 | 1500000                    | 1500000                  | 1530000                | 187500  |
| 45 | 1687500                    | 1687500                  | 1717500                | 187500  |
| 46 | 1875000                    | 1875000                  | 1905000                | 187500  |
| 47 | 2062500                    | 2062500                  | 2092500                | 187500  |
| 48 | 2250000                    | 2250000                  | 2280000                | 187500  |
| 49 | 2437500                    | 2437500                  | 2467500                | 187500  |
| 50 | 2625000                    | 2625000                  | 2655000                | 187500  |
| 51 | 2812500                    | 2812500                  | 2842500                | 187500  |
| 52 | 3000000                    | 3000000                  | 3030000                | 187500  |
| 53 | 3187500                    | 3187500                  | 3217500                | 187500  |

**Figure 4-85:** *Slot allocation pattern using Packet Trace*

The difference is 187500 $\mu$ s.

From the node properties, each node is using 4 slots i.e.  $7.8125[\text{ms}] \times 4 = 31.25[\text{ms}]$ . For 6 nodes, it is  $31.2504[\text{ms}] \times 6 = 187.5[\text{ms}] = 187500[\mu\text{s}]$ . Node 1 transmits packets after every 187500  $\mu$ s.

**Table 4-43:** *Node transmitting in each time slot*

| Node            | 1      | 2      | 3      | 4      | 5      | 6      | 1      | 2      | 3      |
|-----------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Time ( $\mu$ s) | 405080 | 436330 | 467580 | 498830 | 530080 | 561330 | 592580 | 623830 | 655080 |

In the above table, the first row represents the node that is generating the traffic. Compare the above table with packet trace. In TDMA, packet transmission occurs in a serial fashion, with each node taking turns accessing the channel. Channel resources may be underutilized when a node has no packet(s) to transmit in its slot, since each node has access to the entire channel bandwidth in each time slot.

## 5 Model Limitations

- Terrain modeling is not supported.
- Weather effects cannot be modeled.
- Interleaving is not supported.
- All nodes are already associated to the network.
- All nodes are properly synchronized to the global notion of time, and have negotiated a conflict-free slot schedule.
- Only IP is supported for addressing, grouping, multicasting and broadcasting.

## 6 Latest FAQs

Up-to-date FAQs on NetSim's TDMA Radio Networks library are available at

1. <https://tetcos.freshdesk.com/support/solutions/folders/14000110331>