NetSim®

Accelerate Network R & D

Cognitive Radio

A Network Simulation & Emulation Software

By

TETCOS LLP

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1 Introduction

Electromagnetic spectrums allotted to networks such as GSM/HSPA, 3G, 4G, TV, Wi-Fi, defense communication, radio broadcasting, mobile satellites, aeronautical satellites are not always evenly utilized. While some bands in the spectrum are heavily used and overcrowded, some other bands are idle most times and underutilized. This underutilization of bands in the electromagnetic spectrum leads to Spectrum Holes, that are nothing but available channels in the wireless spectrum. These channels are a band of frequencies which are assigned to a primary user, but at times are not utilized by that user.

With the advent of Cognitive Radio (CR), spectrum can be utilized more efficiently. A user who is unable to be serviced by a band, can access a spectrum hole at the correct time and geographic location. Thus, CR is an adaptive, intelligent radio and network technology that can automatically detect spectrum holes and utilize them for data transmission.

NetSim models CR by using the specifications in the IEEE 802.22 standard. Users can also connect a Cognitive Radio with Internetwork devices, use all the protocols that Internetworks support, and view packet and event traces.

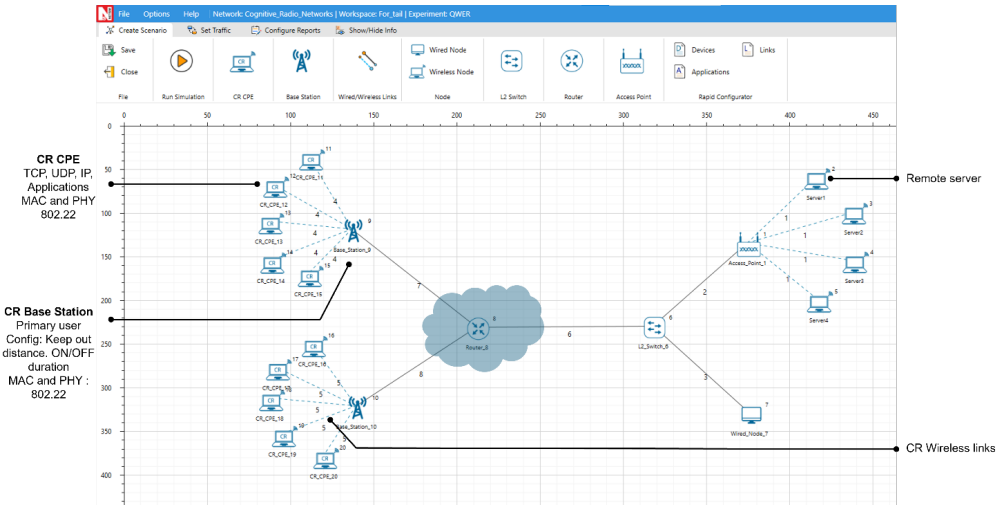


Figure 1-1: *A typical Cognitive Radio Network scenario in NetSim. The topology shows two CR Base Stations communication with CR CPEs and connected to an external network via a Router*

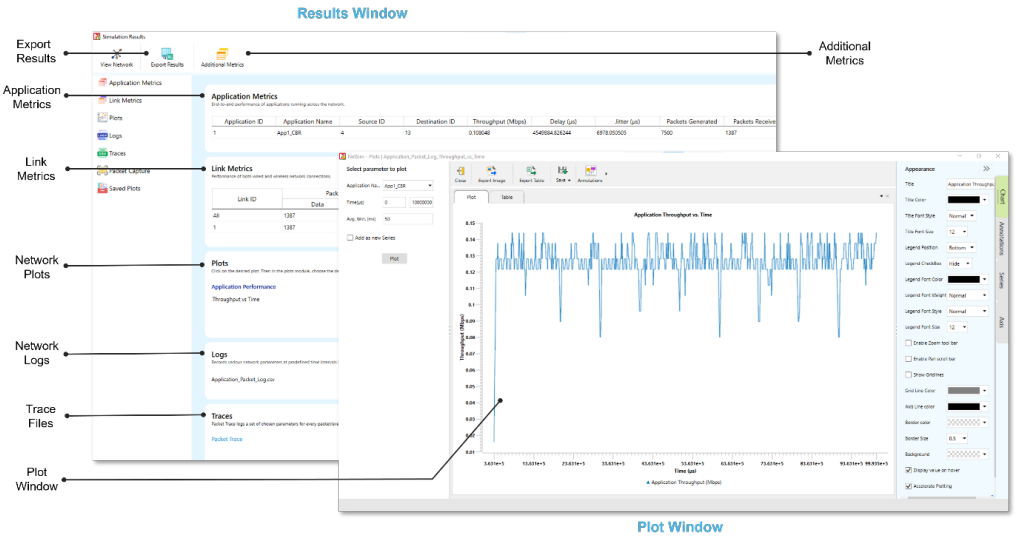


Figure 1-2: *The Result dashboard and Plot window shown in NetSim after completion of simulation*

2 Simulation GUI

Open NetSim and click New Simulation → Cognitive Radio Networks as shown Figure 2-1.

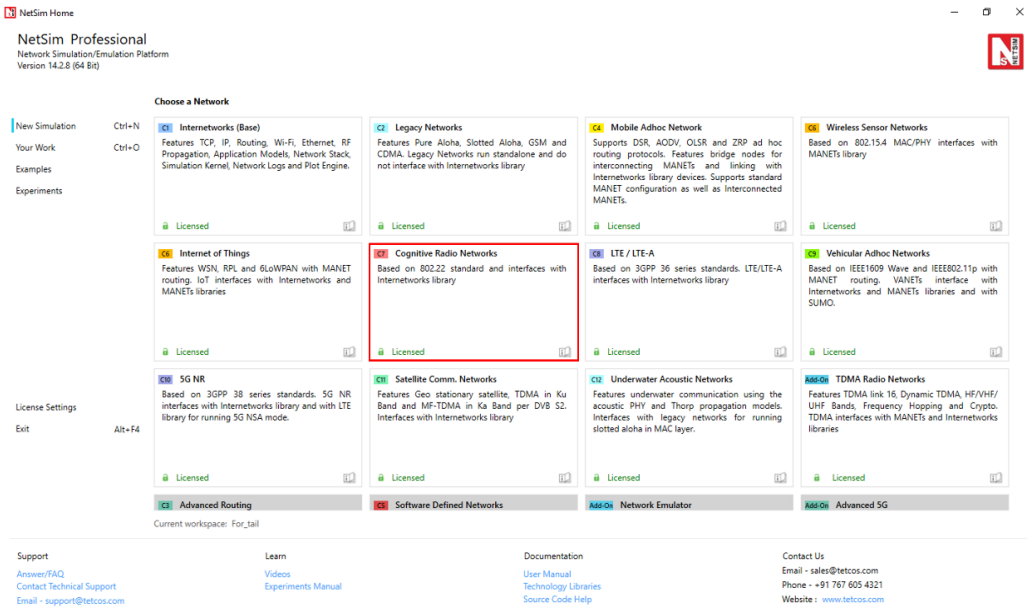


Figure 2-1: *NetSim Home Screen*

2.1 Create Scenario

Cognitive Radio Networks come with a palette of various devices like CR CPE, Base Station L2 Switch, Router, Wired Node, Wireless Node, and AP (Access Point).

2.1.1 Click and drop into environment

- Add a Base Station (BTS) – click the Base Station icon on the toolbar and place the BTS in the grid.
- Add a Cognitive Radio CPE – click the CR CPE icon on the toolbar and place the CR CPE in the grid.
- Add a Switch, Router, Wired Node, Wireless Node, and an Access point – click the appropriate icon on the toolbar and place the device in the grid.

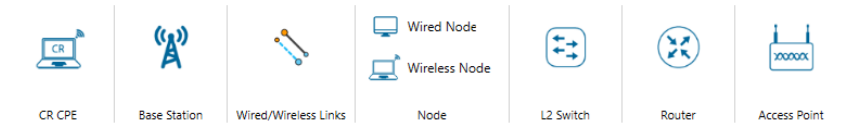


Figure 2-2: *CR Networks Device Palette in GUI*

NOTE: If you change the settings of the grid, then ensure that you place the CPE in the BS's coverage area.

- Connect the devices in the Cognitive Radio network by clicking the Wired/Wireless icon on the toolbar.
- Configure an application as follows:

  - Click on the Set Traffic tab in the top ribbon/toolbar.
  - Select any application from the list and configure the traffic between source and destination.
  - Specify other application parameters per your model.

- Set the properties of the BTS, CR CPE, and other devices as follows:
  - Click on a BTS, CR CPE, or device, then open the right-side properties panel and modify the interface and layer properties as per your requirements.
  - For a BTS, specify incumbent count, minimum and maximum frequency, channel bandwidth, modulation technique, coding rate.

2.2 Enable Packet Trace, Event Trace (Optional)

Click Packet Trace / Event Trace icon in the tool bar and click on OK button. For detailed help, please refer to sections 8.3 and 8.4 of the User Manual. Select Plots icon for enabling Plots and click on OK button see Figure 2-3.

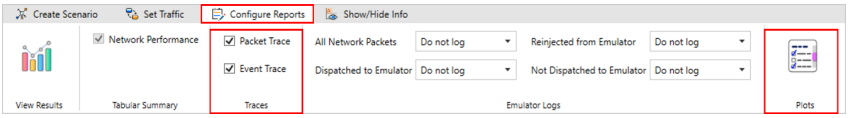


Figure 2-3: *Packet Trace, Event Trace & Plots options on top ribbon*

2.3 GUI Configuration Properties

Table 2-1: *Datalink layer, physical layer properties of CR CPE and Base Station.*

Parameter	Scope	Range	Description
Base station – Interface(Wireless) – Datalink layer			
MAC address	Fixed		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).
Duplexing	Fixed		Duplexing in cognitive radio networks is crucial for efficient spectrum use and interference management, allowing secondary users to leverage TDD and FDD based on spectrum availability to communicate.
Dsx Request Retries	Local	1–7	Number of Timeout Retries on DSA/DSC/DSD Requests. Dynamic Service Addition Requests. This message is sent either by a CPE or BS and is to create a new service flow.
Dsx Response Retries	Local	1–7	Number of Timeout Retries on DSA/DSC/DSD Responses. Dynamic Service Addition Responses. A DSA-RSP message shall be generated in response to a received DSA-REQ message.
T7 (S)	Local	0–1	Waiting Time for DSA/DSC/DSD Response timeout.

Continued on next page

Table 2-1 continued from previous page

Parameter	Scope	Range	Description
T8 (ms)	Local	0–300	Waiting Time for DSA/DSC Acknowledge timeout. Maximum 300 ms. DSA/DSC Acknowledges are sent in response to the DSA-RSP/DSC-RSP Messages.
T31 (ms)	Local	1–16	Waiting time for BLM-REP (Bulk Measurement Report) timeout.
Channel Check Time (s)	Local	0–100	The time during which a channel shall be checked for the presence of licensed incumbent signals having a level above the Incumbent Detection Threshold prior to the commencement of WRAN operation.
Non Occupancy Period (s)	Local	1–60	The required period during which WRAN device transmissions shall not occur in a given channel because of the detected presence of an incumbent signal in that channel above the Incumbent Detection Threshold.
Channel Detection Time (s)	Local	0–2	The maximum time taken by a WRAN device to detect a licensed incumbent signal above the Incumbent Detection Threshold within a given channel during normal WRAN operation.
Probability of false alarm	Local	0 to 1	Probability of false alarm denotes the probability of a CR user declaring that a Primary User is present when the spectrum is actually free.
Channel Move time (s)	Local	0–2	This is the time a WRAN system takes to stop all interfering transmissions on the current channel when it detects a licensed signal above the Incumbent Detection Threshold.
NUM Sensing Period	Local	0–127	The number of times a cognitive radio network will check for other signals (like licensed users) within a specific time window.
Sensing Period Duration	Local	0–1023	Duration of sensing period field (in units of OFDM symbols) in a Sensing Window Specification Array entry.
Sensing Period Interval	Local	0–2047	Sensing Period Interval is the time between each sensing check in a cognitive radio network. This interval determines how often the network pauses to listen for signals.
Candidate Channel Refresh Time	Local	1–10	Maximum time interval allowed before sensing is performed on the candidate channel to ensure that no incumbents are detected.
Backup Channel Refresh Time	Local	1–10	Maximum time interval allowed before sensing is performed on the backup channel to ensure that no incumbents are detected.
Candidate Channel Transition Time	Local	1–100	Minimum time duration without detection of any incumbent for a candidate channel to transition to the backup channel.

Continued on next page

Table 2-1 continued from previous page

Parameter	Scope	Range	Description
Wait Before Channel Move	Local	1–4096	Waiting time before which the BS moves to the first backup channel. This is used to make sure that all the CPEs are ready to move to the backup channel before BS switches operation.
Sensing Mode	Local	0–2	Specifies which SSF (Spectrum Sensing Function) outputs are valid and in some cases it specifies the behavior of the SSF.
ISO Country Code	Local		ISO Code of the Country.
Incumbent Count	Local	0–3	It refers to the number of Incumbents.
Name	Fixed		Name of the incumbent (i.e., Primary user).
ID	Fixed		Incumbent id is identification number of Primary user.
Longitude/X-coordinate	Local	Less than the grid max value	The location of the device on the x-axis or horizontal axis in 'Grid view' and Longitude in 'Map view'.
Latitude/Y-coordinate	Local	Less than the grid max value	The location of the device on Y-axis or vertical axis in 'Grid view' and Latitude in 'Map view'.
Z Coordinate	Fixed		The location of the device on Z-axis. Note: Z-axis is non-editable parameter.
Operating Frequency Start	Local	54–862	Frequency at which incumbent starts.
Operating Frequency End	Local	54–862	Frequency at which incumbent ends.
ON Duration	Local	1–100000	This represents how much time incumbent operates.
OFF Duration	Local	0–100000	Time gap between two successive incumbent operations.
Keep Out Distance (m)	Local	1–500	The maximum distance at which secondary user can detect the primary user. This is the distance between incumbent and the CR-CPE.
Operational Distribution	Local		Constant distribution: the output is constant value. Exponential Distribution: the output is a form of continuous probability distribution.
Base station – Interface(Wireless) – Physical Layer			
Channel bandwidth	Local	6,7,8	Frequency band used to transmit the data. Difference between Maximum frequency and Minimum frequency.
Sampling Factor	Fixed	8/7	This value, together with the bandwidth and the number of subcarriers used, helps determine the useful symbol time.

Continued on next page

Table 2-1 continued from previous page

Parameter	Scope	Range	Description
Modulation Technique	Local	QPSK, 16QAM, 64 QAM	Modulation is the process of varying one waveform in relation to another waveform. It is used to transfer data over an analog channel (i.e. radio link).
Coding Rate	Local	1/2, 2/3, 3/4, 5/6	It states what portion of the total amount of information that is useful (non-redundant). If code rate is k/n then for every k bits of useful information, the coder generates a total of n bits.
Multiple Access	Fixed		OFDMA is a frequency-division multiplexing (FDM) scheme utilized as a digital multi-carrier modulation method.
Transmit Power (mW)	Local	1–5000	It is the signal intensity of the transmitter. The higher the power radiated by the transmitter's antenna the greater the reliability of the communications system. Unit = mW.
FFT Size	Fixed		The effect of fast Fourier transform (FFT) size on detecting narrowband signals is analyzed and appropriate FFT size is suggested to improve the probability of detection.
Cyclic Prefix Factor	Local	1/4, 1/8, 1/16, 1/64	Specifies the size of the cyclic prefix used by the PHY in the frame transmissions in this superframe.
Self-Coexistence	Fixed	No	A state by which wireless communication systems of the same type can share a RF transmission channel in a common area while minimizing harmful interference to each other.
DCD Interval	Fixed	10	Time between transmission of DCD messages. DCD Messages are regular updates sent by the base station to describe channel settings.
UCD Interval	Fixed	10	Time between transmission of UCD messages. UCD Messages are periodic messages sent by the base station to provide connected devices with information about upstream channel settings.
BW Req Backoff Start	Local	0–15	Initial size of BW Request opportunity used by CPEs to contend to send bandwidth requests to BS.
BW Req Backoff End	Local	0–15	Final size of BW Request opportunity used by CPEs to contend to send bandwidth requests to BS.
UCC Response wait time	Local	2	It is the waiting time of BS after it has sent the Channel Switch Request until it gets Channel Switch Response.
TTG (Transmit/Receive Transition Gap)	Fixed	210	TTG gap stands for Transmit Transition Gap. It is provided between downlink and uplink subframe.

Continued on next page

Table 2-1 continued from previous page

Parameter	Scope	Range	Description
Downlink to Uplink Ratio	Local	1:1, 2:2, 3:3, 4:4	It is the ratio of downlink to uplink transmission time.
Intra Frame Quiet Period Cycle Length	Local	0–15	Specified in number of superframes, it indicates the spacing between the superframes for which the intra-frame quiet period specification is valid.
Intra Frame Quiet Period Bitmap	Local	Length>0	Valid only if Claimed Intra-frame Quiet Period Cycle Length >0. Each bit in the bitmap corresponds to one frame.
IFQP Duration (Symbols)	Local	1–16	Valid only if Claimed Intra-frame Quiet Period Cycle Length >0. Indicates the number of symbols starting from the end of the frame during which quiet period applies.
Reference distance (m)	Global	0–10	PL: is the path loss at the reference distance d_0. Unit: Decibel (dB). See propagation model documents for details.
CR-CPE – Interface(Wireless) – Datalink Layer			
BLM REP Retries	Local	0–7	Number of retries allowed for sending BLM-REP.
CR-CPE – Interface(Wireless) – Physical Layer			
T20 (MACframes)	Local	1–16	Time the CPE searches for preambles on a given channel.
Antenna gain (dB)	Local	−1000 to 1000	A relative measure of an antenna's ability to direct or concentrate radio frequency energy in a particular direction or pattern.
Antenna height (m)	Local	1 to 100	Antenna height is only considered when using the following propagation models: Cost 231 Hata Urban, Cost 231 Hata Suburban, Hata Urban, Hata Suburban.

2.4 Run Simulation

Click on Run Simulation icon on the top ribbon/toolbar.

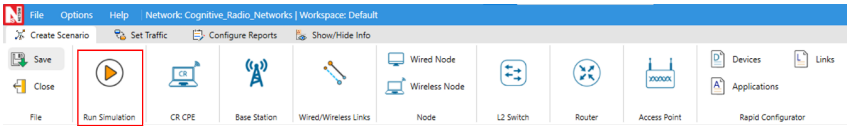


Figure 2-4: *Run Simulation on top ribbon.*

Set the Simulation Time and click on the Run button.

3 Model Features

The following are the 802.22 features implemented in NetSim:

- **Primary user:** A user who has higher priority or legacy rights to use a specific part of the spectrum. Also known as Incumbent user. In NetSim, the primary user is part of the base station.
- **Secondary user:** A user who has a lower priority or legacy rights to use a specific part of the spectrum, and therefore uses the spectrum in such a way that it does not cause interference to the primary users.
- **Keep-out distance:** The minimum distance between the primary user and the secondary user to ensure that there is no interference.
- **Spectrum sensing:** A process of monitoring and sensing the spectrum to capture information such as holes in the spectrum and the interference, and the primary users in the geographical area.

For more information about spectrum sensing in NetSim, see http://www.ieee802.org/22/Meeting_documents/2006_Mar/2
06-0028-05-0000-Spectrum-Sensing-Simulation-Model.doc.

You can find the definition of the Spectrum sensing function the SpectrumManager.c file. If you want to modify this function at run-time, you must write a new sensing algorithm that checks if the incumbent user's signal is present. This changes the keep-out distance.

The following is the Spectrum sensing function:

```
struct stru_802_22_SSFOutput* fn_NetSim_CR_CPE_SSF(struct
stru_802_22_SSFInput* input,NETSIM_ID nDevId,NETSIM_ID nInterfaceId)
```

- **UCS notification:** UCS or Urgent Coexistence Situation notification is a notification that the secondary user sends when it senses that the primary user is back to use the channel. In NetSim, this happens when the distance between the primary user and the secondary user is less than the keep-out distance. UCS notifications are generated at the end of the quiet period (network-wide quiet periods when all network traffic is suspended and the base stations and CPEs perform in-band sensing.
- **Channel switching:** A process where the secondary user switches the channel when the primary user of the channel comes back to use it.

In NetSim, the secondary user does not switch the channel to an adjacent one. The secondary user switches the channel to a channel that is next to an adjacent channel.

For example, if the primary user has returned to channel 1, the secondary user switches to channel 3 and not channel 2.

- **Operating frequency:** The frequency band at which the incumbent operates. This band can range from 54 MHz to 862 MHz. The bandwidth of every channel is 6 MHz.

For example, if the operating frequency is set from 54 MHz to 72 MHz, then

- Channel 1 will be 54 to 60 MHz.
- Channel 2 will be 60 to 66 MHz.
- Channel 3 will be 66 to 72 MHz.

- **ON duration:** The duration of time for which the primary or incumbent user operates.

In NetSim, you can specify a duration between 1 second and 100,000 seconds.

- **OFF duration:** The time interval between two successive ON durations of an incumbent.

For example, if you specify an ON duration on 5 seconds, the incumbent operates once every 5 seconds. If you specify an ON duration of 0, the incumbent remains always active.

PHY rate: The PHY rate in the IEEE 802.22 standard depends on the following parameters:

- Number of bits per symbol
- Coding rate
- Cyclic prefix
- Symbol duration

PHY rate in Cognitive Radio is calculated as follows:

$$\text{PHY rate} = \frac{\text{Bit count in One symbol}}{\text{Symbol duration}} \tag{1}$$

$$\text{Bit count in One symbol} = \text{Subcarrier count} \times \text{Number of bits} \times \text{Coding Rate} \tag{2}$$

$$\text{Bit count in One symbol} = 1440 \times 2 \times 2\left(\frac{1}{2}\right), \quad \text{where Subcarrier count} = 1440 \tag{3}$$

For Subcarrier count, refer the table 201 in the document available here – https://ieeexplore.ieee.org/document/7098301.

The following table lists the different modulation techniques and the number of bits per symbol see Table 3-1, the modulation technique uses.

Table 3-1: *Different Modulation techniques vs. number of bits per symbol*

Modulation technique	# of bits per symbol
QPSK	2
16-QAM	4
64-QAM	6

The following displays the coding rate.

Table 3-2: *Different Coding rates vs. Data bits vs. Redundant bits*

Coding rate	Data bits	Redundant bits (n-k)
1/2 (default)	1	1
2/3	2	1
3/4	3	1
4/5	4	1

The following table displays the cyclic prefix.

Table 3-3: *Cyclic prefix*

Cyclic prefix
1/4
1/8
1/16
1/64

$$\text{Symbol duration} = \frac{\text{Subcarrier spacing}}{\text{Cyclic prefix}} = 317.38 \tag{4}$$

$$\text{Data rate} = \frac{\text{Bit count in One symbol}}{\text{Symbol duration}} = \frac{1440}{317.38} = 4.53 \text{ Mbps} \tag{5}$$

In NetSim, the base station allocates a maximum of One symbol per CPE. If the generation rate is more than the data filled in one symbol, the allocation fails and this results in Zero throughput. The first symbol is reserved for CR control frames or any broadcast PDU.

- **Coding rate:** A fractional number used for error correction. Coding rate specifies what part of the redundant message is meaningful. If the code rate is k/n, for every 'k' bits of useful information, the coder generates a total of 'n' bits of data, of which $n - k$ are redundant.

3.1 How to avoid low Application Layer Throughput

When you simulate a Cognitive Radio network in NetSim, the throughput in the Application layer is lesser than the throughput in the Datalink layer throughput because of the following factors:

- TCP connection establishment.
- ARP set up.
- Service flow created for the CPE to the BS and the BS to the CPE.
- Bandwidth request.

To avoid the above effects:

- Set the application traffic model to Custom.
- Set the Downlink/Uplink ratio to 1:1 so, the BS transmits whatever it receives.
- Run UDP in the Transport layer.
- Use static ARP.
- Run the simulation for more than 100 seconds.

3.2 Segmentation

CR segments packets of 100B. In the application settings if the packet size is greater than 100B, then those packets will be segmented. The segment IDs can be viewed in the packet trace.

3.3 How to Modify Device Parameters at Run-time

For information about how to change the device parameters at run-time, see https://tetcos.freshdesk.com/support/solution

4 Featured Examples

NetSim contains example configuration files to help users simulate and understand the concepts associated with Cognitive Radio. To simulate these examples, click Examples > Cognitive-Radio in the NetSim Home Screen.

Users can change the default parameter values in these examples and see how they impact the Cognitive Radio network.

4.1 CR Keep-out Distance

The Cognitive Radio network you model from the example configuration file meets the following specifications:

- A network with 1 base station and 2 CR CPEs, and a unicast application running on one of the CR CPEs.

NetSim uses the following defaults for this example:

- The unicast application transmits data at a constant bit-rate from CR CPE 2 to CR CPE 3.
- The Simulation runs for 100 seconds.

To simulate the example for CR Keep-out Distance in Cognitive Radio, follow these steps:

Open NetSim and Select Examples > Cognitive Radio Networks > CR Keepout Distance then click on the tile in the middle panel to load the example as shown in below screenshot

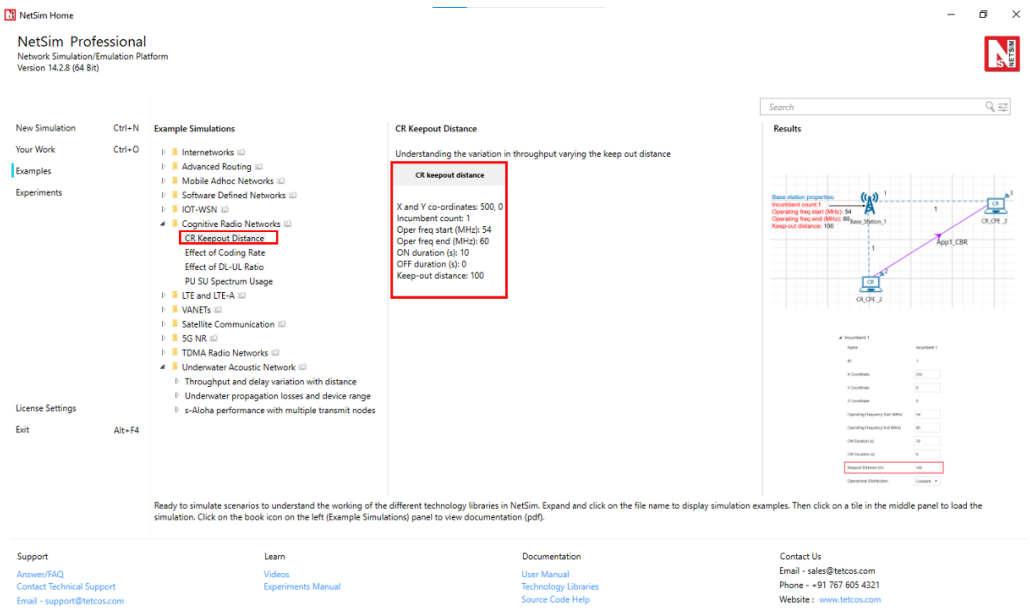


Figure 4-1: *List of scenarios for the example of CR Keepout Distance*

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

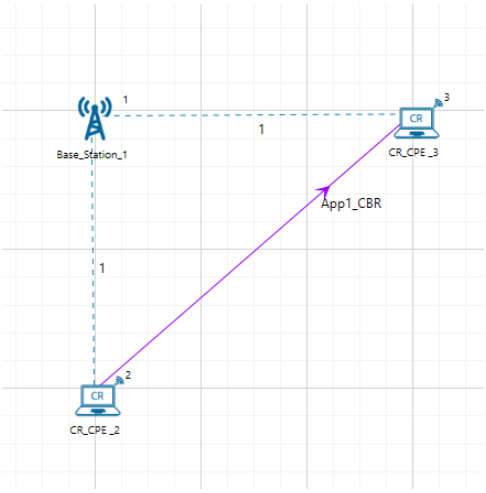


Figure 4-2: *Network set up for studying the CR Keepout Distance*

1. By default, NetSim sets a grid length of 500m x 250m.
2. By default, NetSim sets the Incumbent Count to 2, the range of the operating frequency from 54 MHz to 60 MHz, and incumbent is always ON. To do so:
   (a) Click on Base Station, expand the right-side property panel and set the below properties,
   (b) Go to INTERFACE 1 (COGNITIVE RADIO) → Datalink layer
   (c) The following parameters settings have been made for this example.

- 1 for the Incumbent count field.
- 250, 0 for the X, Y co-ordinates
- 54 for the Oper Freq Start(MHz) field.
- 60 for the Oper Freq End(MHz) field.
- 10 for the ON Duration(s) field.
- 0 for the OFF Duration(s) field.

   (d) The following figure illustrates the CR Bs pop-up window and the default settings see Figure 4-3.

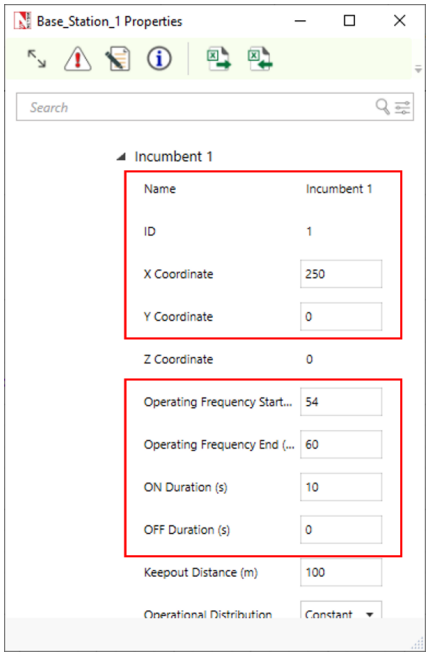


Figure 4-3: *Datalink Layer properties window*

Click on the set traffic tab and create a CBR application between two CR CPEs.

3. Simulate the CR Keep-out Distance for Cognitive Radio example. To do so:
   (a) Click the Run icon located on the toolbar. The Run Simulation pop-up window appear.
   (b) Retain the default settings in the Simulation Configuration tab (Simulation Time = 100).
   (c) After NetSim simulates the CR Keep-out Distance for Cognitive Radio example, NetSim displays the Simulation Results window.
4. Interpret the results. To do so:
   (a) In Simulation results window, click on Additional Metrics and scroll down for Incumbent Metrics under CR Metrics see Figure 4-4.
   (b) Observe the value in the Operational Time (Microsec) and Idle Time (Microsec) column. Because the incumbent is operational throughout the simulation, you will see that the value of the Operational Time is 100 seconds and that of the Idle time is zero (0) seconds. The following Figure 4-4 illustrates step (b).

CR Metrics

Base station metrics

BS Id	Interface id	SCH sent	FCH sent	DSA req recei	DSA rep sent	DSC req recei	DSC rep sent	DSD req recei	DSD rep sent	CHS req sent
1	1	10	150	0	0	0	0	0	0	0

CPE metrics

CPE Id	Interface id	SCH receivec	FCH received	DSA req sent	DSA rep rece	DSC req sent	DSC rep rece	DSD req sent	DSD rep rece	UCS sent	CHS req rece
2	1	10	150	0	0	0	0	0	0	0	0
3	1	10	150	0	0	0	0	0	0	1	0

Incumbent metrics

BS Id	Incumbent id	Frequency(MHz)	Operational time(Microsec	Idle time(Microsec)	Interference time(Microsec
1	1	54-60	100000000	0	1495298

Channel metrics

BS Id	Channel number	Frequency(MHz)	Spectral efficiency
1	1	54-60	0.00538

Figure 4-4: *Incumbent metrics Table*

(c) Click on Application metrics and observe the value in the Throughput (Mbps) column. Because we set the Keep-out distance to 100 and set the incumbent coordinates to outside the Keep-out distance, there is no Interference, and you see a non-zero value for the throughout. The following figure illustrates step (c).

Application Metrics

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

Application ID	Application Name	Source ID	Destination ID	Throughput (Mbps	Delay (µs)	Jitter (µs)
1	App1_CBR	2	3	0.008747	13570.391583	1362.411679

Figure 4-5: *Application Metrics Table*

4.2 Effect of Coding Rate

The Cognitive Radio network modeled in the example configuration file has the following settings:

1. A network with 1 base station, 1 router, 1 wired node and 2 CR CPEs, and a unicast application running on one of the CR CPEs.

NetSim uses the following defaults for this example:

1. The unicast application transmits data at a constant bit-rate from CR CPE 2 to Wired Node 5.
2. The simulation runs for 30 seconds.

To simulate the example Effect of Coding Rate for Cognitive Radio, in NetSim:

Open NetSim and Select Examples > Cognitive Radio Networks > Effect of Coding Rate then click on the tile in the middle panel to load the example as shown in below screenshot

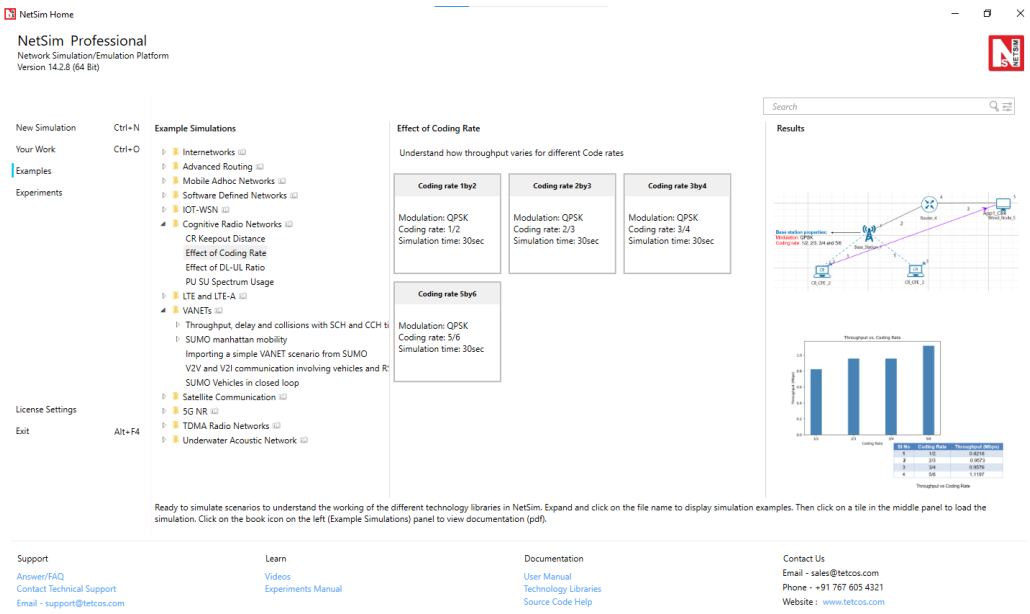


Figure 4-6: *List of scenarios for the example of Effect of Coding Rate*

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

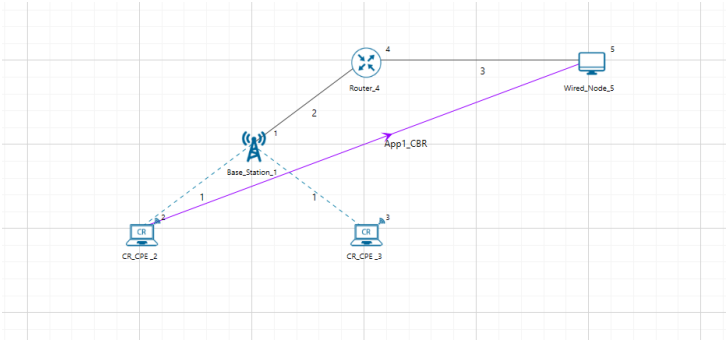


Figure 4-7: *Network set up for studying the Effect of Coding Rate*

1. By default, NetSim sets a grid length of 600m x 300m.
2. By default, NetSim sets the Coding Rate to 1/2. To do so:
   (a) Click on Base Station 1, expand the right-side property panel and set the below properties,
   (b) Click INTERFACE 1 (COGNITIVE RADIO) → Physical layer, see Figure 4-8.
   (c) Coding Rate drop-down list is set to 1/2.
   (d) Click Enter. The following figure illustrates the CR Bs pop-up window and the default settings.

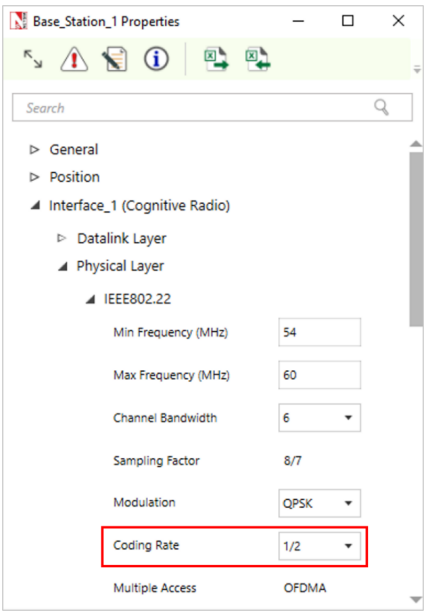


Figure 4-8: *Physical layer window*

3. See that by default, NetSim has not enabled Path Loss for the wireless links between the Base Station and the CR CPEs. To do so:
   (a) Click on the wireless link between Base Station 1 and CR CPE 2 and expand right side property panel and set the Link Properties below
   (b) Channel Characteristics as No pathloss.
4. Configure an application between two nodes by selecting a CBR application from CR-CPE-2 i.e., Source to Wired Node 5 from the Set Traffic tab. Click on the Application and expand the right-side properties set the properties below.
   (a) Packet Size remaining 1460Bytes and Inter Arrival Time remaining 10000μs. Transport Protocol is set to UDP instead of TCP.

5. Simulate the Effect of Coding Rate for Cognitive Radio example. To do so:
   (a) Click the Run icon located on the toolbar.
   (b) The Run Simulation pop-up window appears.
   (c) Retain the default settings in the Simulation Configuration tab (Simulation Time = 30).

After NetSim simulates the Effect of Coding Rate for Cognitive Radio example, NetSim displays the Simulation Results window.

6. Interpret the results. To do so, see the value in the Throughput (Mbps) column, in the Application Metrics Table window see Figure 4-9. You will see a value of 0.8218 Mbps. The following Figure 4-9 illustrates step (6).

Figure 4-9: *Application Metrics Table*

7. Simulate the Effect of Coding Rate for Cognitive Radio example with the following values: 2/3, 3/4, and 5/6. You should see the following values of throughput for the different Coding Rates.

Table 4-1: *Different Coding Rates vs. Throughput*

Sl No	Coding Rate	Throughput (Mbps)
1	1/2	0.8218
2	2/3	0.9573
3	3/4	0.9576
4	5/6	1.1197

You will see that the throughput for #3 is more than that for #2 because, the number of data bits for #3 is more than that for #2, but the number of redundant bits is same. For #2, 2 data bits and 1 redundant bit, and for #3, 3 data bits and 1 redundant bit.

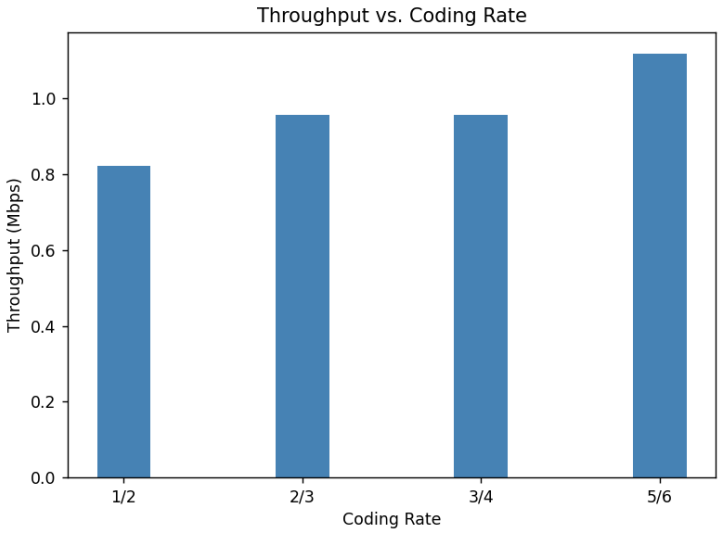


Figure 4-10: *Plot of Coding rate vs Throughput*

Plot

4.3 Effect of Downlink-Uplink Ratio

The Cognitive Radio network you model from the example configuration file meets the following specifications:

- A network with 1 base station, 1 router, 1 Wired node and 2 CR CPEs, and a unicast application running on one of the CR CPEs.

NetSim uses the following defaults for this example:

- The unicast application transmits data at a constant bit-rate from CR CPE 2 to Wired Node 5.
- Simulation runs for 30 seconds.

To simulate the example Effect of Downlink-Uplink Ratio for Cognitive Radio, in NetSim:

Open NetSim and Select Examples > Cognitive Radio Networks > Effect of DL UL Ratio then click on the tile in the middle panel to load the example as shown in below Figure 4-11.

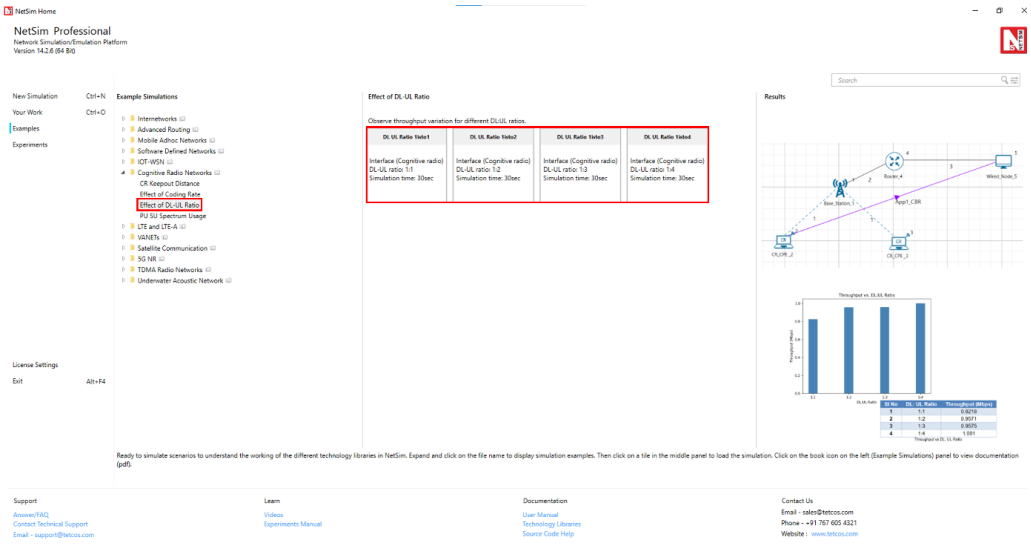


Figure 4-11: *List of scenarios for the example of Effect of DL UL Ratio*

The following network diagram illustrates what the NetSim UI displays when you open the example configuration file Figure 4-12.

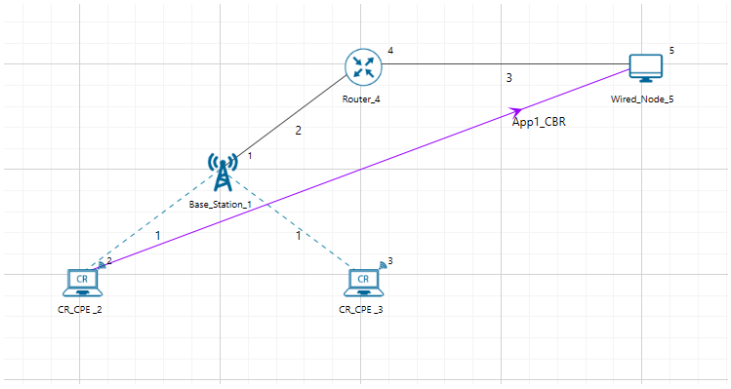


Figure 4-12: *Network set up for studying the Effect of DL UL Ratio*

1. By default, NetSim sets a grid length of 600m x 300m.
2. By default, NetSim sets the Downlink and Uplink ratio to 1:1. To do so:
   (a) Click on Base Station 1, expand the right-side property panel and set the below properties
   (b) Go to INTERFACE 1 (COGNITIVE_RADIO) → PHYSICAL LAYER see Figure 4-13.
   (c) DL UL Ratio drop-down list is set to 1:1.
   (d) The following Figure 4-13 illustrates the CR Bs pop-up window and the default settings.

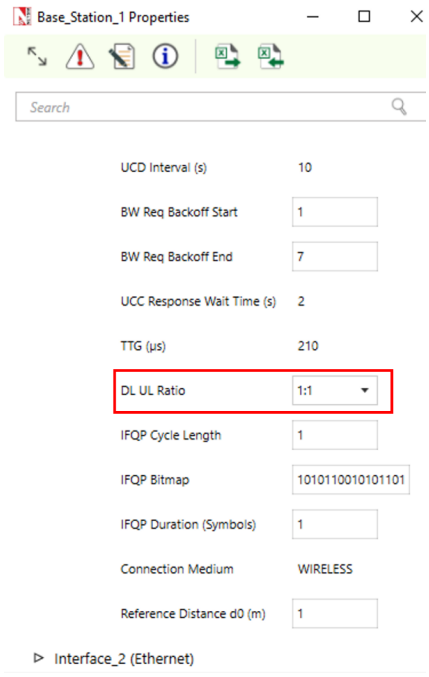


Figure 4-13: *Physical layer window*

3. By default, NetSim has not enabled Path Loss for the wireless links between the Base Station and the CR CPEs. To do so:
   (a) Click on the wireless link between Base Station 1 and CR CPE 2 and expand the right-side property panel and set the Link Properties as Channel Characteristics to No pathloss.
4. Configure an application between two nodes by selecting a CBR application from CR-CPE-2 i.e., Source to Wired Node 5 from the Set Traffic tab. Click on the Application and expand the right-side properties set the properties below.
5. Packet Size remaining 1460Bytes and Inter Arrival Time remaining 10000μs. Transport Protocol is set to UDP instead of TCP.
6. Simulate the Effect of Downlink-Uplink Ratio for Cognitive Radio example. To do so:
   (a) Click the Run icon located on the toolbar. The Run Simulation pop-up window appears.
   (b) Retain the default settings in the Simulation Configuration tab (Simulation Time = 30).
   (c) Click on Run. After NetSim simulates the Effect of Downlink-Uplink Ratio for Cognitive Radio example, NetSim displays the Simulation Results window.
7. Interpret the results. To do so, see the value in the Throughput (Mbps) column, in the Application Metrics Table window see Figure 4-14. You will see a value of 0.8218 Mbps. The following Figure 4-14 illustrates step (6).

Application Metrics

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

Application ID	Application Name	Source ID	Destination ID	Throughput (Mbps	Delay (µs)	Jitter (µs)
1	App1_CBR	2	5	0.821829	5112333.802205	1291.969426

Figure 4-14: *Application Metrics Table*

8. Simulate the Effect of Downlink-Uplink Ratio for Cognitive Radio example with the following Uplink to Downlink ratios: 1:2, 1:3, and 1:4. You should see the following values of throughput for the different Uplink to Downlink ratios see Table 4-2.

Table 4-2: *Different DL: UL Ratio vs. Throughput*

Sl No	DL: UL Ratio	Throughput (Mbps)
1	1:1	0.8218
2	1:2	0.9571
3	1:3	0.9575
4	1:4	1.001

You will see that the throughput for #2 is lesser than that for #3 because, 3 subframes are allocated for upstream and only 1 subframe for downstream. This means more data can be transmitted through the uplink.

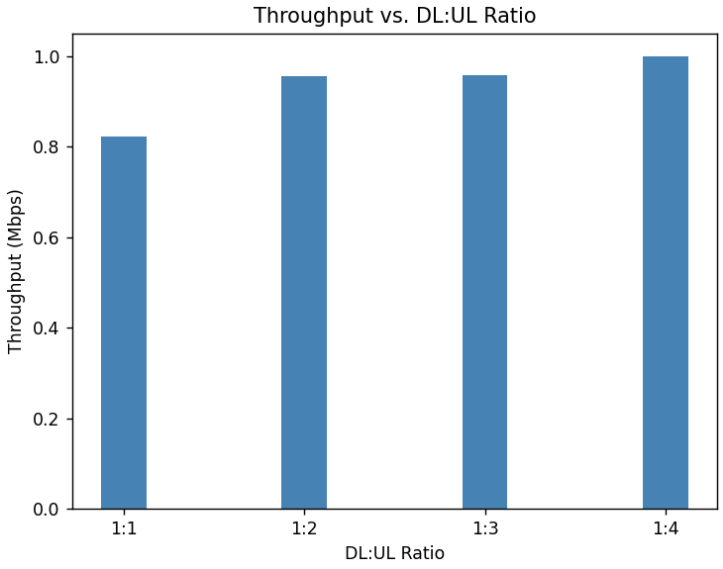


Figure 4-15: *DL:UL ratio vs Throughput*

Plot

4.4 PU SU Spectrum Usage

The Cognitive Radio network modelled from the example configuration file meets the following specifications:

- A network with 1 Base Station and 2 CR CPEs, and a unicast application running on one of the CR CPEs.

NetSim uses the following defaults for this example:

- The unicast application transmits data at a constant bit-rate from CR CPE 2 to CR CPE3.
- Simulation runs for 100 seconds.
- Packet trace is enabled.

To simulate the example for PU and SU's Spectrum Usage for Cognitive Radio, in NetSim:

Open NetSim and Select Examples > Cognitive Radio Networks > PU SU Spectrum Usage then click on the tile in the middle panel to load the example as shown in below screenshot

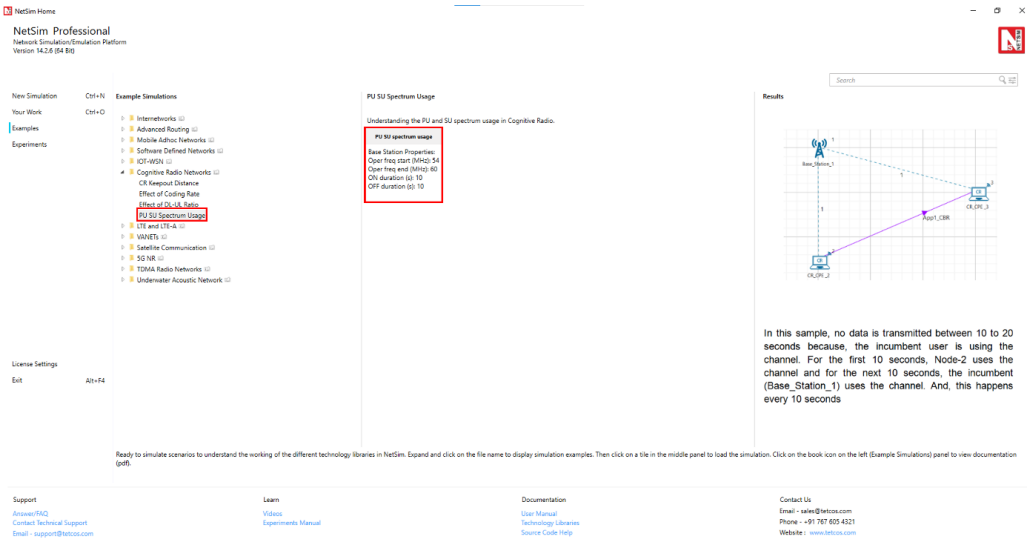


Figure 4-16: *List of scenarios for the example of PU SU Spectrum Usage*

The following network diagram illustrates what the NetSim UI displays when you open the example configuration file see Figure 4-17.

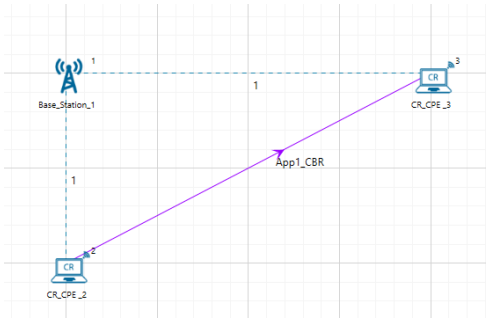


Figure 4-17: *Network set up for studying the PU SU Spectrum Usage*

1. By default, NetSim sets a grid length of 140m x 70m.
2. By default, NetSim sets the Incumbent Count to 2, the range of the operating frequency from 54 MHz to 60 MHz, and incumbent has an OFF period. To do so:
   (a) Click on Base Station 1, expand the right-side property panel and set the below properties
   (b) Go to INTERFACE 1 (COGNITIVE_RADIO) → DATALINK LAYER

(c) Incumbent count drop-down list is set to 1.

(d) NetSim specifies a value of 54 in the Oper Freq Start(MHz) field.

(e) NetSim specifies a value of 60 in the Oper Freq End(MHz) field.

(f) NetSim specifies a value of 10 in the ON Duration(s) field.

(g) NetSim specifies a value of 10 in the OFF Duration(s) field.

(h) The following figure illustrates the CR Bs pop-up window and the default settings see Figure 4-18.

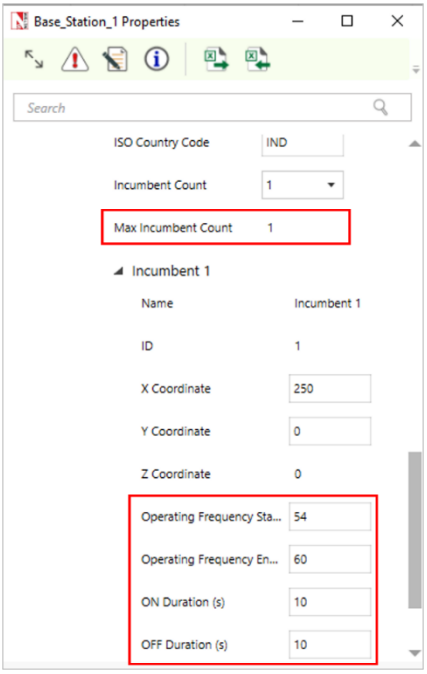


Figure 4-18: *Datalink Layer properties window*

3. Ensure that the distance between incumbent and CR CPEs is less than 100m (keep-out distance).
4. Enable Packet Trace in Configure Reports tab.
5. Simulate the PU SU Spectrum Usage for Cognitive Radio example. To do so:

(a) Click the Run icon located in the ribbon.

(b) The Run Simulation pop-up window appears.

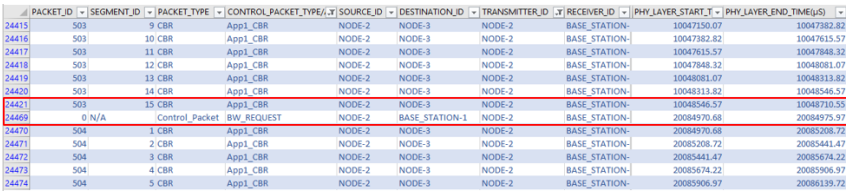
(c) Retain the default settings in the Simulation Configuration tab (Simulation Time = 100).

(d) Click Run. After NetSim simulates the PU SU Spectrum Usage for Cognitive Radio example, NetSim displays the Simulation Results window.

(e) Interpret the results. To do so:

(f) Click Packet Trace in the left area of simulation results window and filter the Packet Type column by CBR and BW Request the Transmitter ID column by Node-2 (CR CPE 2).

(g) See the filtered values in the PHY Layer START time column, in the spreadsheet. Observe that no data is transmitted between 10 to 20 seconds because, the incumbent user is using the channel. For the first 10 seconds, Node-2 uses the channel and for the next 10 seconds, the incumbent (Base Station 1) uses the channel. And, this happens every 10 seconds. The following Figure 4-19 illustrates step (b).



	PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/..	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID	PHY_LAYER_START_T	PHY_LAYER_END_TIME(µS)
24415	503	9	CBR	App1_CBR	NODE-2	NODE-3	NODE-2	BASE_STATION-	10047150.07	10047382.82
24416	503	10	CBR	App1_CBR	NODE-2	NODE-3	NODE-2	BASE_STATION-	10047382.82	10047615.57
24417	503	11	CBR	App1_CBR	NODE-2	NODE-3	NODE-2	BASE_STATION-	10047615.57	10047848.32
24418	503	12	CBR	App1_CBR	NODE-2	NODE-3	NODE-2	BASE_STATION-	10047848.32	10048081.07
24419	503	13	CBR	App1_CBR	NODE-2	NODE-3	NODE-2	BASE_STATION-	10048081.07	10048313.82
24420	503	14	CBR	App1_CBR	NODE-2	NODE-3	NODE-2	BASE_STATION-	10048313.82	10048546.57
24421	503	15	CBR	App1_CBR	NODE-2	NODE-3	NODE-2	BASE_STATION-	10048546.57	10048710.55
24469	0	N/A	Control_Packet	BW_REQUEST	NODE-2	BASE_STATION-1	NODE-2	BASE_STATION-	20084970.68	20084975.97
24470	504	1	CBR	App1_CBR	NODE-2	NODE-3	NODE-2	BASE_STATION-	20084970.68	20085208.72
24471	504	2	CBR	App1_CBR	NODE-2	NODE-3	NODE-2	BASE_STATION-	20085208.72	20085441.47
24472	504	3	CBR	App1_CBR	NODE-2	NODE-3	NODE-2	BASE_STATION-	20085441.47	20085674.22
24473	504	4	CBR	App1_CBR	NODE-2	NODE-3	NODE-2	BASE_STATION-	20085674.22	20085906.97
24474	504	5	CBR	App1_CBR	NODE-2	NODE-3	NODE-2	BASE_STATION-	20085906.97	20086139.72

Figure 4-19: *Packet Trace*

5 Cognitive Radio Networks Experiments in NetSim

Apart from examples, in-built experiments are also available in NetSim. Examples help the user understand the working of features in NetSim while experiments are designed to help the user (usually students) learn networking concepts through simulation. The experiments contain objective, theory, set-up, results, and inference. The following experiments are available in the Experiments manual (pdf file).

1. To analyze how the allocation of frequency spectrum to the Incumbent (Primary) and CR CPE (Secondary User) affects throughput.

6 Reference Documents

IEEE 802.22 - 2011 Standard for Wireless Regional Area Network (WRAN).

7 Latest FAQs

You can refer to the up-to-date FAQs about NetSim's Cognitive Radio library at https://tetcos.freshdesk.com/support/solu