# Cognitive Radio - 802.22

## Contents

# 1 About Cognitive Radio

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.

# 2 Key Concepts of Cognitive Radio

The following are the key concepts involved in the working of a Cognitive Radio network.

- **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/22-06-0028-05-0000-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:

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

  $$Bit\ count\ in\ One\ symbol = Subcarrier\ count \times Number\ of\ bits\ \times Coding\ Rate$$

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

  For Subcarrier count, refer the table on page 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, the modulation technique uses.

  | Modulation technique | # of bits per symbol |
  |---|---|
  | BPSK | 1 |
  | QPSK | 2 |
  | 16-QAM | 4 |

| 64-QAM | 6 |
|---|---|

The following displays the coding rate.

| 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.

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

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

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

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.

## 2.1 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

## 2.2 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/solutions/articles/14000084233-how-do-i-modify-the-cognitive-radio-device-parameters-during-run-time-.

# 3 Simulating Cognitive Radio

To simulate Cognitive Radio in NetSim:

1. Open NetSim and click **New Simulation > Cognitive Radio Networks.**

2. Create a Cognitive Radio by using the following:

   a. Add a Base Station (BTS) – click the Base_Station icon on the toolbar and place the BTS in the grid.

   b. Add a Cognitive Radio CPE – click the CR_CPE icon on the toolbar and place the CR_CPE in the grid.

   c. 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.

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

3. Connect the devices in the Cognitive Radio network by clicking the **Wired/Wireless** icon on the toolbar.

4. Configure an application as follows:

    a. Click the **Application** icon on the toolbar.

    b. Specify the source and destination devices in the network.

    c. Specify other parameters such as method and type of the application.

5. Set the properties of the BTS, CR_CPE, and other devices as follows:

    - Right-click a BTS, CR_CPE, device, click **Properties** and modify the interface and layers' properties to your requirement.

    - For a BTS, specify incumbent count, minimum and maximum frequency, channel bandwidth, modulation technique, coding rate

6. Simulate the Cognitive Radio network as follows:

    a. (Optional) Click the Plots, Packet Trace, and Event Trace icons on the toolbar to enable them.

        For more information about Plots, Packet Trace, and Event Trace, see Chapter 8, Results and Analysis in the User Manual.

    b. Click the Run icon on the toolbar.

    c. Set the simulation time and click **OK**.

# 4 Featured Examples

NetSim contains some example configuration files to let you 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 values of the parameters 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.
- Simulation runs for 100 seconds.

To simulate the example for CR Keep-out Distance for Cognitive Radio, in NetSim:

1. Open NetSim and click **Examples > Cognitive-Radio > CR-Keepout-Distance**. The following network diagram illustrates what the NetSim UI displays when you open the example configuration file.
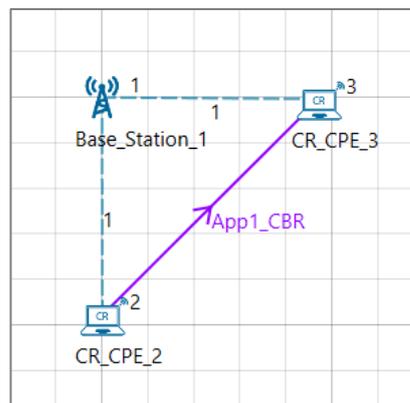


2. See that by default, NetSim has set a grid length of 500m X 500m.

3. See that by default, NetSim has set the Incumbent Count to 1, the range of the operating frequency from 54 MHz to 60 MHz, and incumbent is always ON. To do so:

   a. Right-click **Base_Station_1** and click **Properties.**

      The Cr_Bs pop-up window appears.

   b. Click **INTERFACE_1 (COGNITIVE_RADIO)** in the left area.

   c. Click **DATALINK_LAYER** in the right area.

   d. NetSim has specified a value of **1** in the **Incumbent count** field.

   e. NetSim has specified a value of **500** in the **X_Co_Ordinate** field.

   f. NetSim has specified a value of **0** in the **Y_Co_Ordinate** field.

   g. NetSim has specified a value of **54** in the **Oper_Freq_Start(MHz)** field**.**

   h. NetSim has specified a value of **60** in the **Oper_Freq_End(MHz)** field**.**

   i. NetSim has specified a value of **10** in the **ON_Duration(s)** field**.**

   j. NetSim has specified a value of **0** in the **OFF_Duration(s)** field**.**

   k. Click **OK**. The following figure illustrates the CR_Bs pop-up window and the default settings.
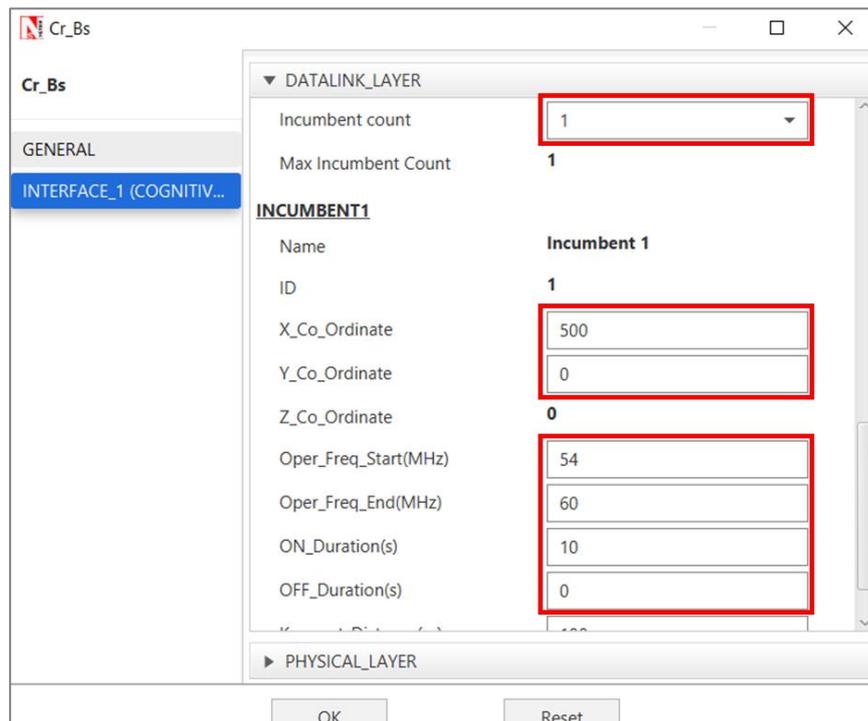


4. Simulate the CR Keep-out Distance for Cognitive Radio example. To do so:

   a. Click the **Run** icon located on the toolbar. The **Run Simulation** pop-up window appears.

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

      c. Click **OK**. After NetSim simulates the CR Keep-out Distance for Cognitive Radio example, NetSim displays the Simulation Results window.

5. Interpret the results. To do so:

      a. Click **CR Metrics > Incumbent metrics** in the left area and check the **Detailed View** check box in the **Incumbent metrics_Table** pop-up window.

      b. Scroll right and see 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 illustrates step (b).



      c. Click **Application_Metrics** in the left area and check the **Detailed View** check box in the **Application_Metrics_Table** pop-up window.

      d. See 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 (d).



## 4.2 PU SU Spectrum Usage

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.
- 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:

1. Open NetSim and click **Examples > Cognitive-Radio > PU-SU-Spectrum-Usage**. The following network diagram illustrates what the NetSim UI displays when you open the example configuration file.
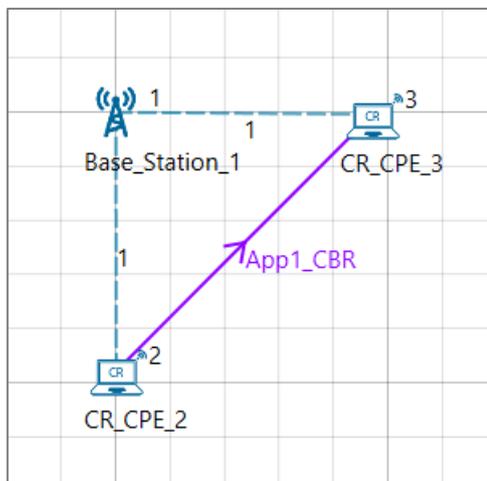


2. See that by default, NetSim has set a grid length of 500m X 500m.

3. See that by default, NetSim has set the Incumbent Count to 1, the range of the operating frequency from 54 MHz to 60 MHz, and incumbent has an OFF period. To do so:

   a. Right-click **Base_Station_1** and click **Properties.** The Cr_Bs pop-up window appears.

   b. Click **INTERFACE_1 (COGNITIVE_RADIO)** in the left area.

   c. Click **DATALINK_LAYER** in the right area.

   d. **Incumbent count** drop-down list is set to **1**.

   e. NetSim has specified a value of **54** in the **Oper_Freq_Start(MHz)** field**.**

   f. NetSim has specified a value of **60** in the **Oper_Freq_End(MHz)** field**.**

   g. NetSim has specified a value of **10** in the **ON_Duration(s)** field**.**

h. NetSim has specified a value of **10** in the **OFF_Duration(s)** field**.**

i. Click **OK**.

4. Ensure that the distance between incumbent and CR CPEs is less than 100m (keep-out distance).

5. Simulate the PU SU Spectrum Usage 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 = 100).

   c. Click **OK**. After NetSim simulates the PU SU Spectrum Usage for Cognitive Radio example, NetSim displays the Simulation Results window.

6. Interpret the results. To do so:

   a. Click **Open Packet Trace** in the left area and filter the **Packet_Type** column by **CBR and** , and the **Transmitter_ID** column by **Node-2 (CR_CPE_2)**.

   b. 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 illustrates step (b).

| | PACKET_ID | SEGMENT_ID | CONTROL_PACKET_TYPE/APP_NAME | TRANSMITTER_ID | RECEIVER_ID | PHY_LAYER_START_TIM | PHY_LAYER_END_TIM |
|---|---|---|---|---|---|---|---|
| 24413 | 503 | 7 | App1_CBR | NODE-2 | BASE_STATION- | 10047001.95 | 10047234.7 |
| 24414 | 503 | 8 | App1_CBR | NODE-2 | BASE_STATION- | 10047234.7 | 10047467.45 |
| 24415 | 503 | 9 | App1_CBR | NODE-2 | BASE_STATION- | 10047467.45 | 10047700.2 |
| 24416 | 503 | 10 | App1_CBR | NODE-2 | BASE_STATION- | 10047700.2 | 10047932.95 |
| 24417 | 503 | 11 | App1_CBR | NODE-2 | BASE_STATION- | 10047932.95 | 10048165.7 |
| 24418 | 503 | 12 | App1_CBR | NODE-2 | BASE_STATION- | 10048165.7 | 10048398.45 |
| 24419 | 503 | 13 | App1_CBR | NODE-2 | BASE_STATION- | 10048398.45 | 10048631.2 |
| 24420 | 503 | 14 | App1_CBR | NODE-2 | BASE_STATION- | 10048631.2 | 10048863.95 |
| 24421 | 503 | 15 | App1_CBR | NODE-2 | BASE_STATION- | 10048863.95 | 10049027.94 |
| 24469 | 0 | N/A | BW_REQUEST | NODE-2 | BASE_STATION- | 20084970.68 | 20084975.97 |
| 24470 | 504 | 1 | App1_CBR | NODE-2 | BASE_STATION- | 20085288.07 | 20085520.82 |
| 24471 | 504 | 2 | App1_CBR | NODE-2 | BASE_STATION- | 20085520.82 | 20085753.57 |
| 24472 | 504 | 3 | App1_CBR | NODE-2 | BASE_STATION- | 20085753.57 | 20085986.32 |
| 24473 | 504 | 4 | App1_CBR | NODE-2 | BASE_STATION- | 20085986.32 | 20086219.07 |

## 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.

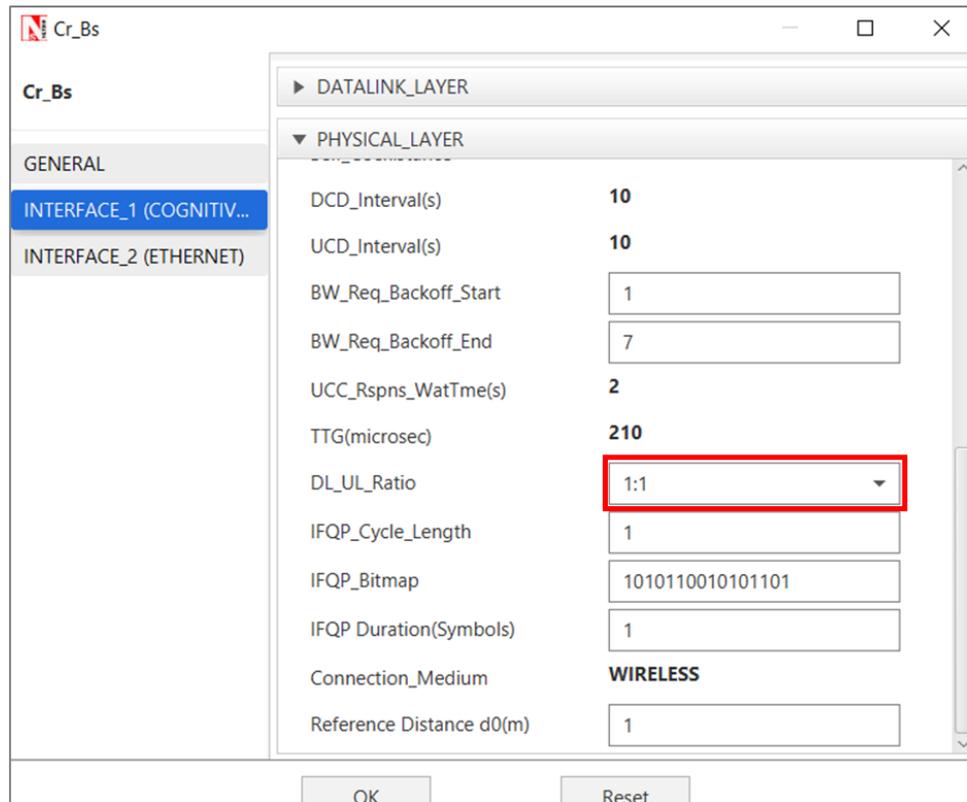NetSim uses the following defaults for this example:

- 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:

1. Open NetSim and click **Examples > Cognitive-Radio > Effect-of-DL-UL-Ratio**. The following network diagram illustrates what the NetSim UI displays when you open the example configuration file.
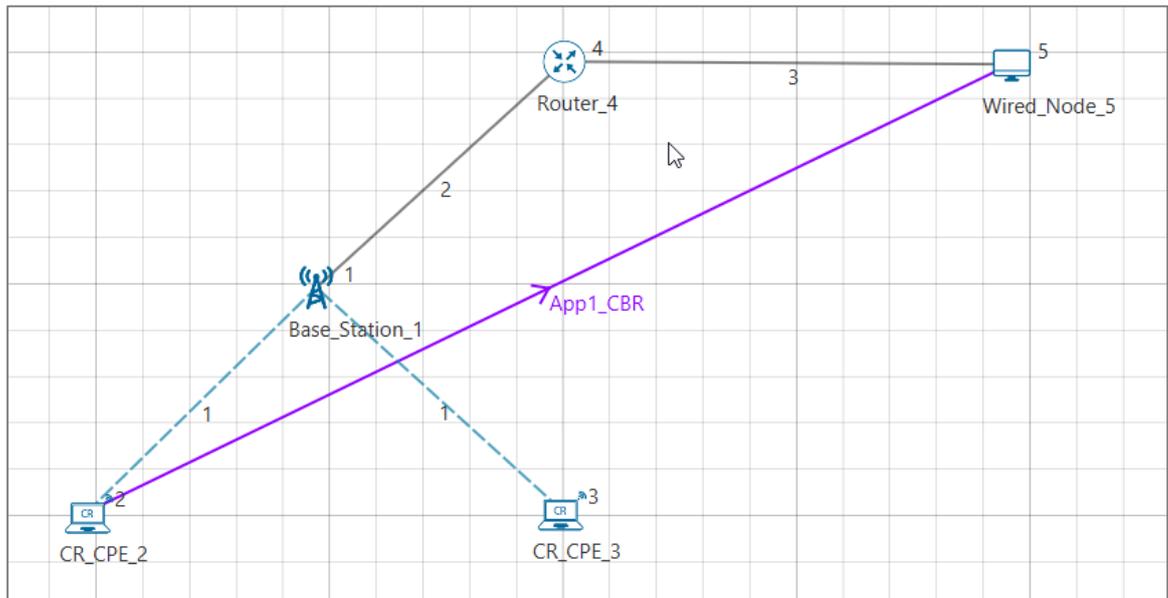


2. See that by default, NetSim has set a grid length of 500m X 500m.

3. See that by default, NetSim has set the Uplink to Downlink ratio to 1:1. To do so:

   a. Right-click **Base_Station_1** and click **Properties.** The Cr_Bs pop-up window appears.

   b. Click **INTERFACE_1 (COGNITIVE_RADIO)** in the left area.

   c. Click **PHYSICAL_LAYER** in the right area.

   d. **DL_UL_Ratio** drop-down list is set to **1:1**.

   e. Click **OK**. The following figure illustrates the CR_Bs pop-up window and the default settings.

4. 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. Right-click the wireless link between Base_Station_1 and CR_CPE_2 and click **Properties.** The Link Properties pop-up window appears.

    b. **Channel_Characteristics** drop-down list is set to **NO_PATHLOSS**.

    c. Click **OK**.

5. 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 **OK**. After NetSim simulates the Effect of Downlink-Uplink Ratio 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. You will see a value of 0.8218 Mbps. The following figure illustrates step (6).

7. 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.

| SI | DL: UL Ratio | Throughput (Mbps) |
|---|---|---|
| 1 | 1:2 | 0.9571 |
| 2 | 1:3 | 0.9575 |
| 3 | 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.

## 4.4 Effect of Coding Rate

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

- 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.

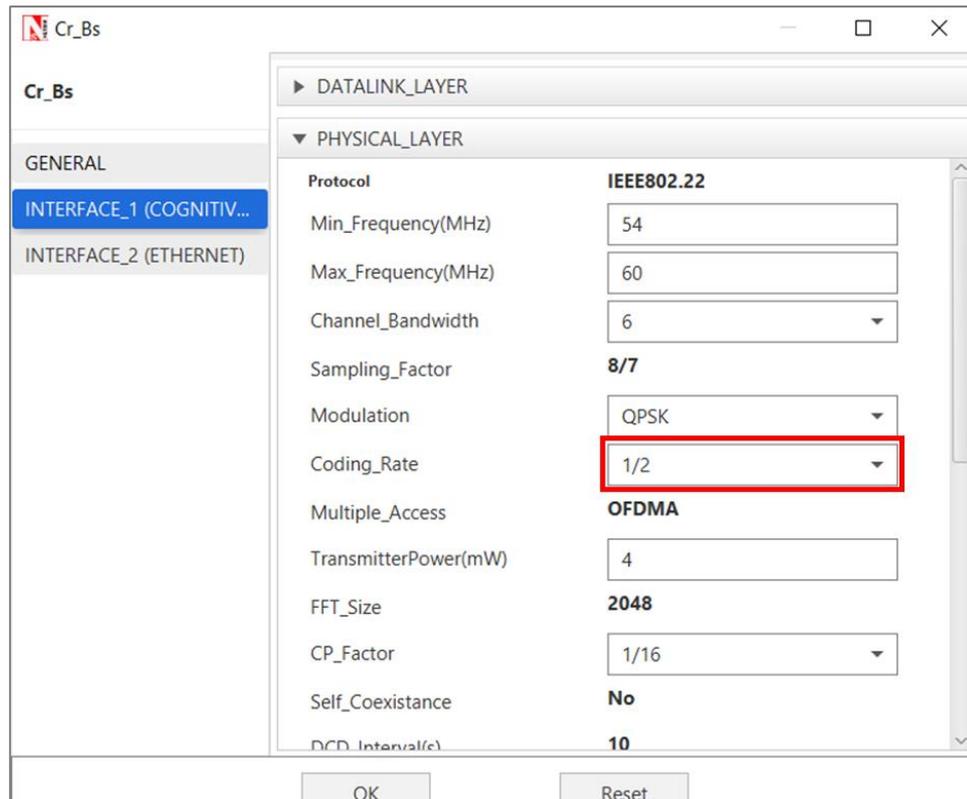NetSim uses the following defaults for this example:

- 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 Coding Rate for Cognitive Radio, in NetSim:

1. Open NetSim and click **Examples > Cognitive-Radio > Effect-of-Coding-Rate**. The following network diagram illustrates what the NetSim UI displays when you open the example configuration file.
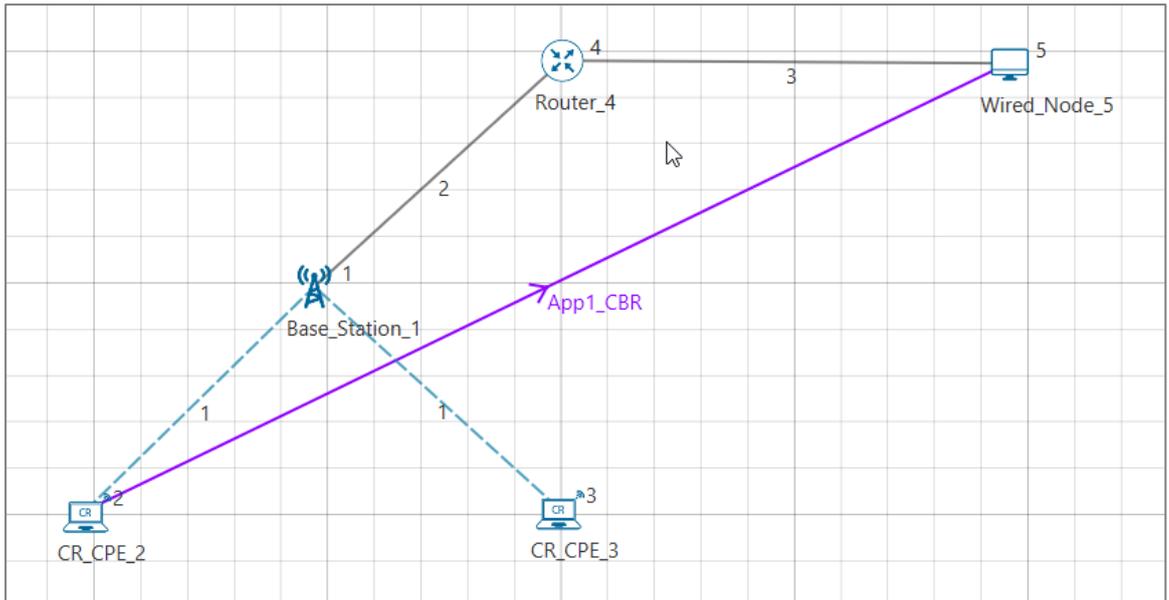
2. See that by default, NetSim has set a grid length of 500m X 500m.

3. See that by default, NetSim has set the Coding Rate to 1/2. To do so:

   a. Right-click **Base_Station_1** and click **Properties.** The Cr_Bs pop-up window appears.

   b. Click **INTERFACE_1 (COGNITIVE_RADIO)** in the left area.

   c. Click **PHYSICAL_LAYER** in the right area.

   d. **Coding_Rate** drop-down list is set to **1/2**.

   e. Click **OK**. The following figure illustrates the CR_Bs pop-up window and the default settings.

4. 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. Right-click the wireless link between Base_Station_1 and CR_CPE_2 and click **Properties.** The Link Properties pop-up window appears.

   b. **Channel_Characteristics** drop-down list is set to **NO_PATHLOSS**.
   c. Click **OK**.

5. Simulate the Effect of Coding Rate 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 **OK**.
      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. You will see a value of 0.8218 Mbps. The following figure illustrates step (6).

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.

| SI | Coding Rate | Throughput (Mbps) |
|----|-------------|-------------------|
| 1  | 2/3         | 0.9573            |
| 2  | 3/4         | 0.9576            |
| 3  | 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.

# 5 Reference Documents

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

# 6 Latest FAQs

You can refer to the up-to-date FAQs about NetSim's Cognitive Radio library at
https://tetcos.freshdesk.com/support/solutions/folders/14000105116