

CRTS

Generated by Doxygen 1.8.6

Fri Feb 19 2016 10:03:34



# Contents

<b>1</b>	<b>CRTS</b>	<b>1</b>
<b>2</b>	<b>Example Scenarios</b>	<b>7</b>
<b>3</b>	<b>Example Cognitive Engines</b>	<b>9</b>
<b>4</b>	<b>Example Cognitive Radio</b>	<b>11</b>
<b>5</b>	<b>Tutorial 1: Running CRTS</b>	<b>13</b>
<b>6</b>	<b>Tutorial 2: Interferers</b>	<b>15</b>
<b>7</b>	<b>Tutorial 3: Writing a Cognitive Engine</b>	<b>17</b>
<b>8</b>	<b>Class Index</b>	<b>23</b>
8.1	Class List . . . . .	23
<b>9</b>	<b>Class Documentation</b>	<b>25</b>
9.1	Cognitive_Engine Class Reference . . . . .	25
9.1.1	Detailed Description . . . . .	25
9.1.2	Member Function Documentation . . . . .	25
9.1.2.1	execute . . . . .	25
9.2	ExtensibleCognitiveRadio Class Reference . . . . .	26
9.2.1	Member Enumeration Documentation . . . . .	30
9.2.1.1	CE_Event . . . . .	30
9.2.1.2	FrameType . . . . .	31
9.2.2	Member Function Documentation . . . . .	31
9.2.2.1	get_rx_subcarrier_alloc . . . . .	31
9.2.2.2	get_tx_subcarrier_alloc . . . . .	31
9.2.2.3	get_tx_taper_len . . . . .	31
9.2.2.4	transmit_frame . . . . .	31
9.2.3	Member Data Documentation . . . . .	32
9.2.3.1	ce_timeout_ms . . . . .	32
9.3	Interferer Class Reference . . . . .	32

9.4	ExtensibleCognitiveRadio::metric_s Struct Reference	33
9.4.1	Detailed Description	34
9.4.2	Member Data Documentation	34
9.4.2.1	CE_event	34
9.4.2.2	control_valid	34
9.4.2.3	frame_num	34
9.4.2.4	payload_len	34
9.4.2.5	payload_valid	35
9.4.2.6	stats	35
9.4.2.7	time_spec	35
9.5	node_parameters Struct Reference	35
9.6	ExtensibleCognitiveRadio::rx_parameter_s Struct Reference	36
9.6.1	Detailed Description	37
9.6.2	Member Data Documentation	37
9.6.2.1	cp_len	37
9.6.2.2	numSubcarriers	37
9.6.2.3	rx_dsp_freq	37
9.6.2.4	rx_freq	37
9.6.2.5	rx_gain_uhd	37
9.6.2.6	rx_rate	38
9.6.2.7	subcarrierAlloc	38
9.6.2.8	taper_len	38
9.7	ExtensibleCognitiveRadio::rx_statistics Struct Reference	38
9.8	Scenario_Controller Class Reference	38
9.9	scenario_parameters Struct Reference	39
9.10	timer_s Struct Reference	39
9.11	ExtensibleCognitiveRadio::tx_parameter_s Struct Reference	39
9.11.1	Detailed Description	40
9.11.2	Member Data Documentation	40
9.11.2.1	cp_len	40
9.11.2.2	fgprops	40
9.11.2.3	numSubcarriers	41
9.11.2.4	subcarrierAlloc	41
9.11.2.5	taper_len	41
9.11.2.6	tx_dsp_freq	41
9.11.2.7	tx_freq	41
9.11.2.8	tx_gain_soft	41
9.11.2.9	tx_gain_uhd	42
9.11.2.10	tx_rate	42





# Chapter 1

## CRTS

### About:

The Cognitive Radio Test System (CRTS) provides a flexible framework for over the air test and evaluation of cognitive radio (CR) networks. Users can rapidly define new testing scenarios involving a large number of CR's and interferers while customizing the behavior of each node individually. Execution of these scenarios is simple and the results can be quickly visualized using octave/matlab logs that are kept throughout the experiment.

CRTS evaluates the performance of CR networks by generating network layer traffic at each CR node and logging metrics based on the received packets. Each CR node will create a virtual network interface so that CRTS can treat it as a standard network device. Part of the motivation for this is to enable evaluation of UDP and TCP network connections. The CR object/process can be anything with such an interface. We are currently working on examples of this in standard SDR frameworks e.g. GNU Radio. A block diagram depicting the test process run on a CR node by CRTS is depicted below.

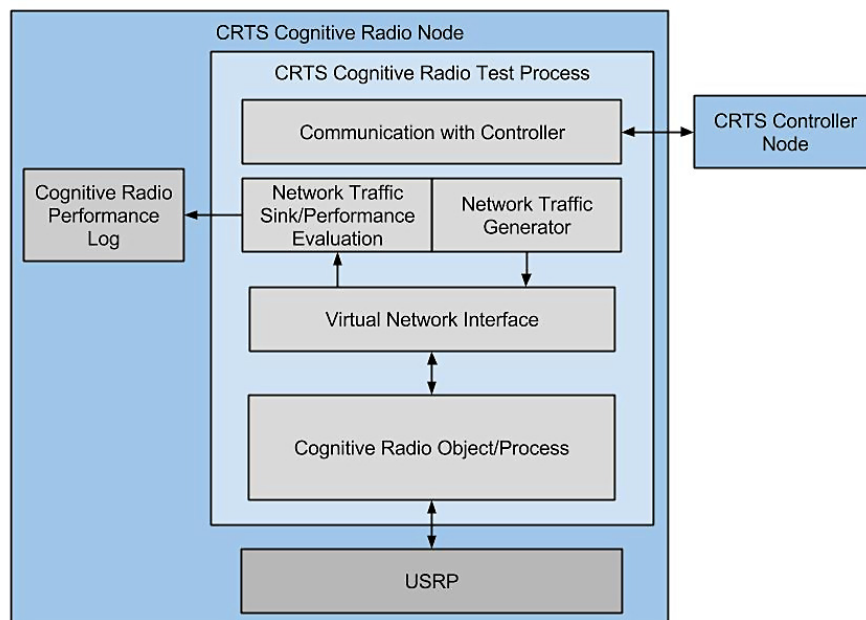


Figure 1.1: Cognitive Radio Test Process

A particular CR has been developed with the goal of providing a flexible generic structure to enable rapid development and evaluation of cognitive engine (CE) algorithms. This CR is being called the Extensible Cognitive Radio (ECR). In this structure, a CE is fed data and metrics relating to the current operating point of the radio. It can then

make decisions and exert control over the radio to improve its performance. A block diagram of the ECR is shown below.

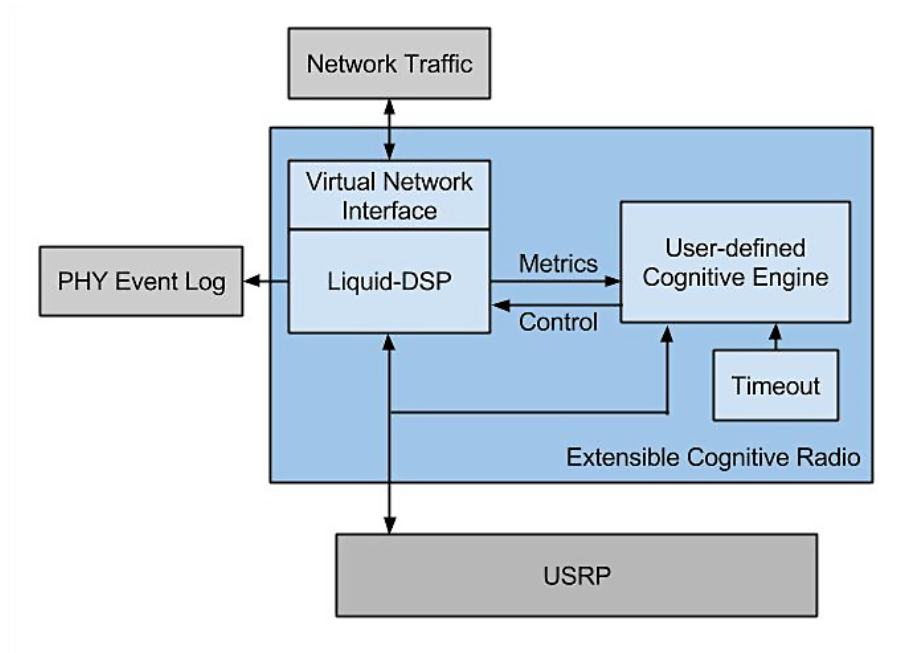


Figure 1.2: The Extensible Cognitive Radio

The ECR uses the [OFDM Frame Generator](#) of [liquid-dsp](#) and uses an [Ettus](#) Universal Software Radio Peripheral (USRP).

CRTS is being developed using the [CORNET](#) testbed under Virginia Tech's [Wireless](#) Research Group.

## Installation:

### Dependencies

CRTS is being developed on [Ubuntu 14.04](#) but should be compatible with most Linux distributions. To compile and run CRTS and the ECR, your system will need the following packages. If a version is indicated, then it is recommended because it is being used in CRTS development.

- [UHD Version 3.8.4](#)
- [liquid-dsp commit a4d7c80d3](#)
- [libconfig-dev](#)

CRTS also relies on each node having network synchronized clocks. On CORNET this is accomplished with Network Time Protocol (NTP). Precision Time Protocol (PTP) would work as well.

Note to CORNET users: These dependencies are already installed for you on all CORNET nodes.

### Downloading and Configuring CRTS

Official releases of CRTS can be downloaded from the [Releases Page](#) while the latest development version is available on the main [Git Page](#).

Note that because using CRTS involves actively writing and compiling cognitive engine code, it is not installed like traditional software.



## Official Releases

1. Download the Version 1.0 tar.gz from the [Official Releases Page](#):

```
$ wget -O crts-v1.0.tar.gz https://github.com/ericps1/crts/archive/v1.0.tar.gz
```

2. Unzip the archive and move into the main source tree:

```
$ tar xzf crts-v1.0.tar.gz
$ cd crts-v1.0/
```

3. Compile the code with:

```
$ make
```

4. Then configure the system to allow certain networking commands without a password (CORNET users should skip this step):

```
$ sudo make install
```

The last step should only ever need to be run once. It configures the system to allow all users to run certain very specific networking commands which are necessary for CRTS. They are required because CRTS creates and tears down a virtual network interface upon each run. The commands may be found in the `.crts_sudoers` file.

To undo these changes, simply run:

```
$ sudo make uninstall
```

## Latest Development Version

1. Download the git repository:

```
$ git clone https://github.com/ericps1/crts.git
```

2. Move into the main source tree:

```
$ cd crts/
```

3. Compile the code with:

```
$ make
```

4. Then configure the system to allow certain networking commands without a password (CORNET users should skip this step):

```
$ sudo make install
```

The last step should only ever need to be run once. It configures the system to allow all users to run certain very specific networking commands which are necessary for CRTS. They are required because CRTS creates and tears down a virtual network interface upon each run. The commands may be found in the `.crts_sudoers` file.

To undo these changes, simply run:

```
$ sudo make uninstall
```

## An Overview

CRTS is designed to run on a local network of machines, each with their own dedicated USRP. A single node, the `CRTS_controller`, will automatically launch each radio node for a given scenario and communicate with it as the scenario progresses.

Each radio node could be

1. A member of a CR network (controlled by `CRTS_CR`) or
2. An interfering node (controlled by `CRTS_interferer`), generating particular noise or interference patterns against which the CR nodes must operate.

## Scenarios

The `master_scenario_file.cfg` specifies which scenario(s) should be run for a single execution of the `CRTS_controller`. A single scenario can be run multiple times if desired. The syntax `scenario_<#>` and `reps_scenario_<#>` must be used.

Scenarios are defined by configuration files in the `scenarios/` directory. Each of these files will specify the number of nodes in the experiment and the duration of the experiment. Each node will have additional parameters that must be specified. These parameters include but are not limited to:

- The node's type: CR or interferer.
- The node's local IP address.
- If it is a CR node, it further defines:
  - The type of the CR (e.g. if it uses the ECR or some external CR).
  - The node's virtual IP address in the CR network.
  - The virtual IP address of the node it initially communicates with.
  - The network traffic pattern (stream, burst, or Poisson)
  - If the CR node uses the ECR, it will also specify:
    - \* Which cognitive engine to use.
    - \* The initial configuration of CR.
    - \* What type of data should be logged.
- If it is an interferer node, it further defines:
  - The type of interference (e.g. OFDM, GMSK, RRC, etc.).
  - The parameters of the interferer's operation.
  - What type of data should be logged.

In some cases a user may not care about a particular setting e.g. the forward error correcting scheme. In this case, the setting may be neglected in the configuration file and the default setting will be used.

Examples of scenario files are provided in the `scenarios/` directory of the source tree.

## The Extensible Cognitive Radio

As mentioned above the ECR uses an OFDM based waveform defined by `liquid-dsp`. The cognitive engine will be able to control the parameters of this waveform such as number of subcarriers, subcarrier allocation, cyclic prefix length, modulation scheme, and more. The cognitive engine will also be able to control the settings of the RF front-end USRP including its gains, sampling rate, center frequency, and digital mixing frequency. See the code documentation for more details.

Currently the ECR does not support much in the way of MAC layer functionality, e.g. there is no ARQ or packet segmentation/concatenation. This is planned for future development.

## Cognitive Engines in the ECR

The Extensible Cognitive Radio provides an easy way to implement generic cognitive engines. This is accomplished through inheritance i.e. a particular cognitive engine can be implemented as a subclass of the cognitive engine base class and seamlessly integrated with the ECR. The general structure is such that the cognitive engine has access to any information related to the operation of the ECR via `get()` function calls as well as metrics passed from the receiver DSP. It can then control any of the operating parameters of the radio using `set()` function calls defined for the ECR.

The cognitive engine is defined by an `execute` function which can be triggered by several events. The engine will need to respond accordingly depending on the type of event that occurred. The event types include the reception of a physical layer frame, a timeout, or USRP overflows and underruns.

To make a new cognitive engine a user needs to define a new cognitive engine subclass. The `CE_Template.cpp` and `CE_Template.hpp` can be used as a guide in terms of the structure, and some of the other examples show how the CE can interact with the ECR. Once the CE has been defined it can be integrated into CRTS by running `$ ./config_CEs` in the top directory.

Other source files in the `cognitive_engine` directory will be automatically linked into the build process. This way you can define other classes that your CE could instantiate. To make this work, a cpp file that defines a CE must be named beginning with "CE\_" as in the examples.

- Any cpp files defining a cognitive engine must begin with "CE\_" as in the examples! \*

Installed libraries can also be used by a CE. For this to work you'll need to manually edit the makefile by adding the library to the variable `LIBS` which is located at the top of the makefile and defines a list of all libraries being linked in the final compilation.

One particular function that users should be aware of is `ECR.set_control_information()`. This provides a generic way for cognitive radios to exchange control information without impacting the flow of data. The control information is 6 bytes which are placed in the header of the transmitted frame. It can then be extracted in the cognitive engine at the receiving radio. A similar function can be performed by transmitting a dedicated control packet from the CE.

Examples of cognitive engines are provided in the `cognitive_engines/` directory.

### Cognitive Radios in Python

Along with cognitive engines defined by the ECR, CRTS also supports cognitive radios written in python. An example of a very simple python cognitive radio can be found in `cognitive_radios/python_txx.py`. When using a python radio, the scenario file must specify the `cr_type` ("python") and a `python_file` (`python_txx.py` in the example scenario). The python file must be in the top-level `cognitive_radios` folder. In addition, you can supply arguments to pass to your radio by using the `arguments` field. An example scenario file for a python radio can be found in `scenarios/Python_Flowgraph_Example.cfg`.

### Interferers

The testing scenarios for CRTS may involve generic interferers. There are a number of parameters that can be set to define the behavior of these interferers. They may generate CW, GMSK, RRC, OFDM, or Noise waveforms. Their behavior can be defined in terms of when they turn off and on by the period and duty cycle settings, and there frequency behavior can be defined based on its type, range, dwell time, and increment.

### Logs

CRTS will log packet transmission and reception details at the network layer if the appropriate flags are set in the scenario configuration file. Each entry will include the number of bytes sent or received, the packet number, and a timestamp. These may be used to look at network layer metrics such as dropped packets or latency. Note that latency calculations can only be as accurate as the synchronization between the server nodes.

The ECR will also log frame transmission and reception parameters and metrics at the physical layer if the appropriate flags are set in the scenario configuration file.

All of the aforementioned logs are written as binary files in the `/logs/bin` directory during the scenario's execution. These logs will be automatically converted to either Python or Octave/Matlab scripts and placed in the `/logs/octave` or `/logs/python` directories after the scenario has finished. These scripts provide the user with an easy way to import data from experiments. Other scripts can then be written to analyze these results. We've provided some basic Octave/Matlab scripts which plot the contents of the logs as a function of time and display some basic statistics.

In the case where a scenario is run more than once (using the `scenario_reps` field in the `master_scenario_file.cfg`), the data from all repetitions will be held in a single Octave script. Rather than a single array for each parameter there will be a cell array for each parameter, each element of the cell array is an array which comprises the results from a particular repetition. This is done to facilitate analysis across the repetitions.



## Chapter 2

# Example Scenarios

### 1. Two\_Channel\_DSA

This simple DSA scenario assumes that there are two CRs operating in FDD and with two adjacent and equal bandwidth channels (per link) that they are permitted to use. A nearby interferer will be switching between these two channels on one of the links, making it necessary for the CR's to dynamically switch their operating frequency to realize good performance.

### 2. Two\_Channel\_DSA\_PU

This simple DSA scenario assumes that there are two radios considered primary users (PU) and two cognitive secondary user (SU) radios. There are two adjacent and equal bandwidth channels (per link) that the cognitive radios are permitted to use. The PU's will switch their operating frequency as defined in their "cognitive engines," making it necessary for the SU CR's to dynamically switch their operating frequency to realize good performance and to avoid significantly disrupting the PU links.

### 3. Two\_Node\_FDD\_Network

This scenario creates the most basic two node CR network. No actual cognitive/adaptive behavior is defined by the cognitive engines in this scenario, it is intended as the most basic example for a user to become familiar with CRTS. Note how initial subcarrier allocation can be defined in three ways. In this scenario, we use the standard allocation method which allows you to define guard band subcarriers, central null subcarriers, and pilot subcarrier frequency, as well as a completely custom allocation method where we specify each subcarrier or groups of subcarriers. In this example we use both methods to create equivalent subcarrier allocations.

### 4. Three\_Node\_HD\_Network

This scenario defines a 3 node CR network all operating on a single frequency, making it half duplex. This was intended as a demonstration of the networking interfaces of the ECR. Note that there is currently no mechanism to regulate channel access e.g. CSMA.

### 5. FEC\_Adaptation

This example scenario defines two CR's that will adapt their transmit FEC scheme based on feedback from the receiver. A dynamic interferer is introduced to make adaptation more important.

## 6. Interferer\_Test

This scenario defines a single interferer (used for development/testing)

## 7. Mod\_Adaptation

This example scenario defines two CR's that will adapt their transmit modulation scheme based on feedback from the receiver. A dynamic interferer is introduced to make adaptation more important.

## 8. Subcarrier\_Alloc\_Test

This example scenario just uses a single node to illustrate how subcarrier allocation can be changed on the fly by the CE. If you run `uhd_fft` on a nearby node before running this scenario you can observe the initial subcarrier allocation defined in the scenario configuration file followed by switching between a custom allocation and the default liquid-dsp allocation.

## 9. Python\_Flowgraph\_Example

This scenario demonstrates how to setup and use a cognitive radio written in python rather than the ECR.

## Chapter 3

# Example Cognitive Engines

We have put together several example CE's to illustrate some of the features and capabilities of the ECR. Users are encouraged to reference these CE's to get a better understanding of the ECR and how they might want to design their own CE's, but should be aware that there is nothing optimal about these examples.

### 1. CE\_Two\_Channel\_DSA\_Link\_Reliability

This CE is intended for the 2 Channel DSA scenario. It operates by switching channels whenever it detects that the link is bad, assuming the source of error to be from the interferer. Once the decision is made at the receiver, the node will update control information transmitted to the other node, indicating the new frequency it should transmit on.

### 2. CE\_Two\_Channel\_DSA\_PU

This CE is used to create a primary user for the 2 Channel DSA PU scenario. The PU will simply switch it's operating frequencies at some regular interval.

### 3. CE\_Two\_Channel\_DSA\_Spectrum\_Sensing

This CE is similar to the first CE listed, but makes its adaptations based on measured channel power rather than based on reliability of the link. The transmitter changes its center frequency based on sensed channel power whereas the receiver will change its center frequency when it has not received any frames for some period of time.

### 4. CE\_FEC\_Adaptation

This CE determines which FEC scheme is appropriate based on the received signal quality and updates its control information so that the transmitter will use the appropriate scheme. This is just a demonstration, no particular thought was put into the switching points.

### 5. CE\_Mod\_Adaptation

This CE determines which modulation scheme is appropriate based on the received signal quality and updates its control information so that the transmitter will use the appropriate scheme. This is just a demonstration, no particular thought was put into the switching points.

### 6. CE\_Template

This CE makes no adaptations but serves as a template for creating new CE's.

## 7. CE\_Subcarrier\_Alloc

This CE illustrates how a CE can change the subcarrier allocation of its transmitter. The method for setting the receiver subcarrier allocation is identical.



## Chapter 4

# Example Cognitive Radio

### 1. `python_txrx.py`

This is a simple python flowgraph that was developed using GNURadio-companion. It reads data from the tunCRTS virtual interface using the TUNTAP\_PDU block, and passes it along to a second node via a Socket\_PDU block operating in server mode. The second node receives the data from a Socket PDU block operating in client mode, then passes it to the TUNTAP PDU block to write the data to the tunCRTS virtual interface. This radio can be used as a template for other python radios, by replacing the Socket\_PDU blocks with USRP blocks to send the data over the air, rather than over the network.



## Chapter 5

# Tutorial 1: Running CRTS

In this tutorial we go over the basic mechanics of how to configure CRTS to run a test scenario or a batch of test scenarios and view the results.

Begin by selecting a set of three nodes that you will use to run a basic scenario using CRTS. Be sure to choose nodes that are close enough for reliable communication. If you are using CORNET, choose three adjacent nodes. You can view the floorplan at [. This floorplan also shows the status for each node. Be sure to choose nodes that are bright green, indicating that they have working USRP's.](#)

Once you've selected three nodes, open ssh terminals to them by running the command below. If you are using CORNET, the username will be your CORNET username. Note that the node ports are also displayed on the floorplan.

```
$ ssh -XC -p <node port>=<""> <username>@128.173.221.40
```

If you didn't check the CORNET floorplan to see that your nodes had working USRP's or if you're using a testbed other than CORNET, run the following command on each node to double check.

```
$ uhd_find_devices
```

If a node does not have access to it's USRP either power cycle the USRP if you have access to it or just try another node.

Navigate to the `crts` directory on each node and open up the `master_scenario_file.cfg` file. This file defines the number of scenarios that will be run when CRTS is executed along with their names and optionally how many times these scenarios should be repeated. In this tutorial we're going to run the `Two_Node_FDD_Network` scenario, which consists of two cognitive radio nodes that will communicate with one another. The contents of the `master\scenario\file.cfg` should look as shown below.

```
NumberofScenarios = 1; reps_all_scenarios = 1; scenario_1 = "Two_Node_FDD_Network";
```

Now open the scenario configuration file `Two_Node_FDD_Network.cfg`. As mentioned earlier, this file defines a basic scenario involving two CR nodes. Familiarize yourself with the overall structure, you may also look at the `Scenario_Template.cfg` file for a detailed description of all the parameters. In this scenario we use the `CE_Template` cognitive engine which does not make any decisions. Check to make sure that all of the print and log flags are set to 1 so that we can view results during and after the scenario runs.

Now that we've looked at how scenarios are configured in CRTS, lets actually run one. First launch the controller. CRTS can be run in a 'manual' or 'automatic' mode. The default behavior is to run in automatic mode; manual mode is specified by a `-m` flag after the controller command. Manual mode can be very useful for debug purposes when you develop complex cognitive engines later on. On the node you want to act as the controller, run:

```
$ ./CRTS_controller -m
```

Now you can run the CRTS cognitive radio process on the other two nodes.

```
$ ./CRTS_CR -a <controller ip>=<"">
```

The controller IP needs to be specified so the program knows where to connect.

On CORNET the internal ip will be `192.168.1.<external port number -6990>`. Observe that the two nodes have

received their operating parameters and will begin to exchange frames. Over the air metrics for the received frames should be printed out to both terminals.

Once the scenario has finished running go to the /logs/octave directory. You should see several auto-generated .m files starting with Two\_Node\_FFD\_Network\_\*. To view a plot of the network throughput vs. time for each node run:

```
$ octave
```

```
Two_Node_FDD_Network_Node<node number>_NET_RX Plot_CR_NET_RX
```

You can also view plots of the physical layer transmitted and received frames.

```
Two_Node_FDD_Network_Node<node number>_PHY_TX Plot_CR_PHY_TX
```

```
Two_Node_FDD_Network_Node<node number>_PHY_RX Plot_CR_PHY_RX
```

Troubleshooting:

- If you are seeing issues with your links e.g. no frames are being received or there is a significant number of frames being received in error, a first measure check would be to look at the transmit and receive gains for each node. Depending on the physical placement of the nodes and the environment you may need to use higher gains to overcome path loss or in some cases you may need to reduce your gain to avoid clipping the ADC of the USRP.
- If you don't see the generated octave log files, return to the scenario file and make sure all of the options including the word log are set equal to 1.

## Chapter 6

# Tutorial 2: Interferers

In this tutorial we go over how to use an interferer in a CRTS test scenario and the options available in terms of defining the interferers behavior.

As in the previous tutorial, select a set of three nearby nodes in your testbed and open ssh terminals to each.

Modify master/\_scenario/\_file.cfg to run the Interferer\_Test scenario. The contents of the file should then include the following definitions.

```
NumberofScenarios = 1; reps_all_scenarios = 1; scenario_1 = "Interferer_Test";
```

Now open the Interferer\_Test.cfg file to see the scenario definition. You may also refer to the Scenario\_Template.cfg file for a detailed description of each parameter for an interferer node. For the first execution let's set the following parameters.

```
tx_rate = 1e6; interference_type = "RRC"; period = 4.0; duty_cycle = 1.0; tx_freq_behavior = "FIXED";
```

On another node, open uhd\_fft so that we can see the interferer's transmissions; run the following command

```
$ uhd_fft -f <tx_freq> -s <tx_rate> -g <gain>
```

where tx\_freq and tx\_rate are the parameters defined in the Interferer\_Test.cfg file, and gain should be set based on the physical separation of the nodes. On CORNET, a gain of 10-20 dB is usually good.

You should now see a plot of the spectrum where the interferer will transmit. If there is already a signal present you may want to change to a different band (one which you have a license for of course). To do so you'll need to change tx\_freq in the scenario file.

Return to the first node and run the CRTS controller

```
$ ./CRTS_controller -m
```

Finally on a third node run

```
$ ./CRTS_interferer -a <controller ip>="">
```

You should now see a constant signal in the middle of the spectrum. It should have the root-raised-cosine shape.

Now go back to the scenario file and edit the duty cycle to be 0.5. Rerun CRTS and you should see the same signal which will alternate between being on for duty\_cycle\*period seconds and then off for (1-duty\_cycle)\*period.

Now let's look at dynamic frequency behavior. Go back to the scenario file and set the following properties

```
duty_cycle = 1.0; tx_freq_behavior = "SWEEP"; tx_freq_min = <tx_freq-5e6>; tx_freq_max = <tx_freq+5e6>;  
tx_freq_dwell_time = 1.0; tx_freq_resolution = 1.0e6;
```

Also make sure the log flags are set as shown below.

```
log_phy_tx = 1; generate_octave_logs = 1;
```

Close uhd\_fft and rerun it so we can see the full band the interferer will be transmitting in:

```
$ uhd_fft -f <tx_freq> -s 10e6 -g <gain>
```

Rerun CRTS and you should now see a signal which will sweep back and forth across the viewable spectrum,

changing frequencies once every second.

Now move into the /logs/octave directory. You should see a file called Interferer\_Test\_Int\_PHY\_TX.m. If you do, run the following to see a plot of the interferer's transmission parameters as a function of time throughout the scenario's execution.

```
$ octave
```

```
Interferer_Test_Node1_Int_PHY_TX Plot_Interferer_PHY_TX
```

If you'd like, play around with some of the settings. You might try changing tx\_freq\_behavior to "RANDOM", changing the interference\_type, or trying some combination of dynamic frequency behavior and a duty cycle.

## Chapter 7

# Tutorial 3: Writing a Cognitive Engine

In this tutorial we go through the procedure to define a new cognitive engine, make it available to the ECR, and run a scenario with it. If you haven't already, you may find it useful to review the documentation on the ECR and CE's found in the CRTS-Manual.pdf useful.

Specifically we'll be making a simple CE which calculates some statistics and prints them out periodically. We'll also demonstrate how the CE can exert control over the ECR's operation and observe how this impacts the statistics. The statistics we will track include the number of received frames, the average error vector magnitude, the average packet error rate, and the average received signal strength indicator. We'll also modify the transmit gain periodically so that we'll observe some changes in the statistics over time.

Move to the `cognitive_engine` directory in your local CRTS repository. Make copies of the cognitive engine template files. Note that in order to properly integrate the CE into CRTS, the header and source files should begin with 'CE\_' This is done to identify the CE sources so that they can be integrated into the ECR code.

```
$ cp CE_Template.cpp CE_Tutorial_3.cpp $ cp CE_Template.hpp CE_Tutorial_3.hpp
```

With these two files we will be defining a new class for our cognitive engine. Edit both files so that each instance of 'CE\_Template' is replaced with 'CE\_Tutorial\_3'. Also edit the define statements at the top of the header file from `CE_TEMPLATE` to `CE_TUTORIAL_3`.

Now open up `CE_Tutorial_3.hpp` so we can add some necessary class members. We'll need timers in order to know when to print the statistics out and update the transmitter gain along with constants to represent how frequently this should be done and by how much the transmit gain should be increased. We'll also need a counter for the number of frames received and how many were invalid. Finally, we'll need to sum the error vector magnitude and received signal strength indicator. So in total we need to add the following members.

```
const float print_stats_period_s = 1.0;
timer print_stats_timer;
const float tx_gain_period_s = 1.0;
const float tx_gain_increment = 1.0;
time tx_gain_timer;
int frame_counter;
int frame_errs;
float sum_evm;
float sum_rssi;
```

Now open up `CE_Tutorial_3.cpp` so we can implement our CE. First we need to initialize all of our members in the constructor like so:

```
print_stats_timer = timer_create();
timer_tic(print_stats_timer);
tx_gain_timer = timer_create();
timer_tic(tx_gain_timer);
frame_counter = 0;
frame_errs = 0;
sum_evm = 0.0;
sum_rssi = 0.0;
```

Let's also make sure we clean up the timers in the destructor.

```
timer_destroy(print_stats_timer);
timer_destrpy(tx_gain_timer);
```

Now let's move on to the core of the CE, the execute function. Note that the template has set up a generic structure to deal with each of the possible events which can trigger the CE execution. So at this point we should be considering what we want to happen for each event. We need to keep update the class members to keep track of the statistics of interest. All of these statistics are based on received frames, so we should update them whenever a PHY event happens. Add the following code under the switch case for PHY events.

```
frame_counter++;
if (!ECR->CE_metrics.payload_valid)
    frame_errs++;
sum_evm += pow(10.0, ECR->CE_metrics.stats.evm/10.0);
sum_rssi += pow(10.0, ECR->CE_metrics.stats.rssi/10.0);
```

Note that EVM and RSSI are reported in dB, but to acquire an average we need to convert to linear units.

We said that we wanted to print statistics every print\_stats\_period\_s seconds. This doesn't depend on a particular event, so let's write this functionality in a block of code before the event switch. We want to check the elapsed time, print the statistics if enough time has elapsed, and then we'll need to reset the variables used to track statistics. We should also cover the case when zero frames have been received. Something like the following should do the trick.

```
if(timer_toc(print_stats_timer) > print_stats_period_s){
    if (frame_counter>0) {
        printf("Updated Received Frame Statistics:\n");
        printf("  Frames Received: %i\n", frame_counter);
        printf("  Average EVM:      %f\n", 10.0*log10(sum_evm/(float)frame_counter));
        printf("  Average PER:      %f\n", (float)frame_errs/(float)frame_counter);
        printf("  Average RSSI:     %f\n", 10.0*log10(sum_rssi/(float)frame_counter));

        // reset timer and statistics
        timer_tic(print_stats_timer);
        frame_counter = 0;
        frame_errs = 0;
        sum_evm = 0.0;
        sum_rssi = 0.0;
    } else {
        printf("Updated Received Frame Statistics:\n");
        printf("  Frames Received: 0\n");
        printf("  Average EVM:      -\n");
        printf("  Average PER:      -\n");
        printf("  Average RSSI:     -\n");
    }
}
```

Note that we report EVM and RSSI in dB and so must apply another conversion.

Now that we have written code to track and display some statistics on the received frames, let's make a modification to the ECR's transmission so We need to make sure that the gain stays within the possible values, something like below would work. This should be placed above the event switch just as the other timer-based code.

```
if(timer_toc(tx_gain_timer) > tx_gain_period_s){
    timer_tic(tx_gain_timer);

    float current_tx_gain = ECR->get_tx_gain();
    if(current_tx_gain < 25.0)
        ECR->set_tx_gain(current_gain + tx_gain_increment);
    else
        ECR->set_tx_gain(0.0);
}
```

Now that we've established the desired functionality for our CE, we need to configure CRTS so that we can use it, and recompile the code. This is accomplished simply by running the following from the CRTS root directory.

```
$ ./config_CEs $ make
```

Next, we'll need to define a scenario that uses this new CE. Since we'll just be using two CR's, move to the scenario directory and copy the Two\_Node\_FDD\_Network scenario.

```
$ cd scenarios $ cp Two_Node_FDD_Network.cfg Tutorial_3.cfg
```

Open up Tutorial\_3.cfg. At the very top let's change the run time to be a bit longer.



```
run_time = 60.0;
```

Let's also edit both nodes to have an initial transmit gain of 0, and of course we need to use our new CE. Let's also disable metric printing so we can focus on the statistics we've used in our CE. Make the following changes for both nodes.

```
tx_gain = 0;
CE = "CE_Tutorial_3";
print_metrics = 0;
```

The last thing we need to do is make sure the master\_scenario\_file.cfg has the right information so our new scenario will run. Edit the file to look like below.

```
NumberOfScenarios = 1;
reps_all_scenarios = 1;
scenario_1 = "Tutorial_3";
```

Now we can run the scenario using the same procedure as in Tutorial\_1. Login to three nodes on your testbed.

On node 1: \$ ./CRTS\_controller -m

On nodes 2 and 3: \$ ./CRTS\_CR -a <controller ip>="">

You should see updated statistics being printed to the screen once every second on nodes 2 and 3. You should further observe decreasing EVM and increasing RSSI. Note that depending on the distance between the two nodes you may not detect frames at the lower gain settings or you might have distortion/clipping issues at the higher gains levels.

If you are having troubles here are the completed files that you can compare against.

// CE\_Tutorial\_3.hpp

```
#ifndef _CE_TUTORIAL_3_
#define _CE_TUTORIAL_3_

#include "CE.hpp"
#include "timer.h"

class CE_Tutorial_3 : public Cognitive_Engine {
private:
    // internal members used by this CE
    const float print_stats_period_s = 1.0;
    timer print_stats_timer;
    const float tx_gain_period_s = 1.0;
    const float tx_gain_increment = 1.0;
    timer tx_gain_timer;
    int frame_counter;
    int frame_errs;
    float sum_evm;
    float sum_rssi;

public:
    CE_Tutorial_3();
    ~CE_Tutorial_3();
    virtual void execute(ExtensibleCognitiveRadio *ECR);
};

#endif
```

// CE\_Tutorial\_3.cpp

```
#include "ECR.hpp"
#include "CE_Tutorial_3.hpp"

// constructor
CE_Tutorial_3::CE_Tutorial_3() {
    print_stats_timer = timer_create();
    timer_tic(print_stats_timer);
    tx_gain_timer = timer_create();
    timer_tic(tx_gain_timer);
    frame_counter = 0;
    frame_errs = 0;
    sum_evm = 0.0;
```

```

    sum_rssi = 0.0;
}

// destructor
CE_Tutorial_3::~CE_Tutorial_3() {
    timer_destroy(print_stats_timer);
    timer_destroy(tx_gain_timer);
}

// execute function
void CE_Tutorial_3::execute(ExtensibleCognitiveRadio *ECR) {

    if (timer_toc(tx_gain_timer) > tx_gain_period_s) {
        timer_tic(tx_gain_timer);

        float current_tx_gain = ECR->get_tx_gain_uhd();
        if (current_tx_gain < 25.0)
            ECR->set_tx_gain_uhd(current_tx_gain + tx_gain_increment);
        else
            ECR->set_tx_gain_uhd(0.0);
    }

    if (timer_toc(print_stats_timer) > print_stats_period_s) {
        timer_tic(print_stats_timer);

        if (frame_counter > 0) {
            printf("Updated Received Frame Statistics:\n");
            printf("  Frames Received: %i\n", frame_counter);
            printf("  Average EVM:      %f\n", 10.0*log10(sum_evm/(float)frame_counter));
            printf("  Average PER:      %f\n", (float)frame_errs/(float)frame_counter);
            printf("  Average RSSI:     %f\n", 10.0*log10(sum_rssi/(float)frame_counter));

            // reset statistics
            frame_counter = 0;
            frame_errs = 0;
            sum_evm = 0.0;
            sum_rssi = 0.0;
        } else {
            printf("Updated Received Frame Statistics:\n");
            printf("  Frames Received: 0\n");
            printf("  Average EVM:      -\n");
            printf("  Average PER:      -\n");
            printf("  Average RSSI:     -\n");
        }
    }

    switch(ECR->CE_metrics.CE_event) {
        case ExtensibleCognitiveRadio::TIMEOUT:
            // handle timeout events
            break;
        case ExtensibleCognitiveRadio::PHY:
            // handle physical layer frame reception events
            frame_counter++;
            if (!ECR->CE_metrics.payload_valid)
                frame_errs++;
            sum_evm += pow(10.0, ECR->CE_metrics.stats.evm/10.0);
            sum_rssi += pow(10.0, ECR->CE_metrics.stats.rssi/10.0);
            break;
        case ExtensibleCognitiveRadio::UHD_OVERFLOW:
            // handle UHD overflow events
            break;
        case ExtensibleCognitiveRadio::UHD_UNDERRUN:
            // handle UHD underrun events
            break;
        case ExtensibleCognitiveRadio::USRP_RX_SAMPS:
            // handle samples received from the USRP when simultaneously
            // running the receiver and performing additional sensing
            break;
    }
}

```

### // Tutorial\_3.cfg

```

// general scenario parameters
num_nodes = 2;
run_time = 60.0;

// Node 1
node1 : {
    // general node parameters
    type = "CR";
    cr_type = "ecr";
    CORNET_IP = "192.168.1.38";

    // network parameters

```

---

```

CRTS_IP = "10.0.0.2";
TARGET_IP = "10.0.0.3";
net_traffic_type = "stream";
net_mean_throughput = 2e6;

// cognitive engine parameters
CE = "CE_Tutorial_3";
ce_timeout_ms = 200.0;

// log/report settings
print_metrics = 0;
log_phy_rx = 1;
log_phy_tx = 1;
log_net_rx = 1;
log_net_tx = 1;
generate_octave_logs = 1;

// initial USRP settings
rx_freq = 862.5e6;
rx_rate = 2e6;
rx_gain = 10.0;
tx_freq = 857.5e6;
tx_rate = 2e6;
tx_gain = 0.0;

// initial liquid OFDM settings
duplex = "FDD";
tx_gain_soft = -12.0;
tx_modulation = "bpsk";
tx_crc = "crc32";
tx_fec0 = "v27";
tx_fec1 = "none";
// tx_cp_len = 16;
// rx_cp_len = 16;

tx_subcarriers = 32;
tx_subcarrier_alloc_method = "standard";
tx_guard_subcarriers = 4;
tx_central_nulls = 6;
tx_pilot_freq = 4;

rx_subcarriers = 32;
rx_subcarrier_alloc_method = "standard";
rx_guard_subcarriers = 4;
rx_central_nulls = 6;
rx_pilot_freq = 4;
};

// Node 2
node2 : {
    // general node parameters
    type = "CR";
    cr_type = "ecr";
    CORNET_IP = "192.168.1.39";

    // virtual network parameters
    CRTS_IP = "10.0.0.3";
    TARGET_IP = "10.0.0.2";
    net_traffic_type = "stream";
    net_mean_throughput = 2e6;

    // cognitive engine parameters
    CE = "CE_Tutorial_3";
    ce_timeout_ms = 200.0;

    // log/report settings
    print_metrics = 0;
    log_phy_rx = 1;
    log_phy_tx = 1;
    log_net_rx = 1;
    log_net_tx = 1;
    generate_octave_logs = 1;

    // initial USRP settings
    rx_freq = 857.5e6;
    rx_rate = 2e6;
    rx_gain = 10.0;
    tx_freq = 862.5e6;
    tx_rate = 2e6;
    tx_gain = 0.0;

    // initial liquid OFDM settings
    duplex = "FDD";
    tx_gain_soft = -12.0;
    tx_modulation = "bpsk";
    tx_crc = "crc32";
    tx_fec0 = "v27";

```

---

```

tx_fec1 = "none";
tx_delay_us = 1e3;
// tx_cp_len = 16;
// rx_cp_len = 16;

tx_subcarriers = 32;
tx_subcarrier_alloc_method = "custom";
tx_subcarrier_alloc : {
    // guard band nulls
    sc_type_1 = "null";
    sc_num_1 = 4;

    // pilots and data
    sc_type_2 = "pilot";
    sc_type_3 = "data";
    sc_num_3 = 3;
    sc_type_4 = "pilot";
    sc_type_5 = "data";
    sc_num_5 = 3;
    sc_type_6 = "pilot";

    // central nulls
    sc_type_7 = "null";
    sc_num_7 = 6;

    // pilots and data
    sc_type_8 = "pilot";
    sc_type_9 = "data";
    sc_num_9 = 3;
    sc_type_10 = "pilot";
    sc_type_11 = "data";
    sc_num_11 = 3;
    sc_type_12 = "pilot";

    // guard band nulls
    sc_type_13 = "null";
    sc_num_13 = 4;
}

rx_subcarriers = 32;
rx_subcarrier_alloc_method = "custom";
rx_subcarrier_alloc : {
    // guard band nulls
    sc_type_1 = "null";
    sc_num_1 = 4;

    // pilots and data
    sc_type_2 = "pilot";
    sc_type_3 = "data";
    sc_num_3 = 3;
    sc_type_4 = "pilot";
    sc_type_5 = "data";
    sc_num_5 = 3;
    sc_type_6 = "pilot";

    // central nulls
    sc_type_7 = "null";
    sc_num_7 = 6;

    // pilots and data
    sc_type_8 = "pilot";
    sc_type_9 = "data";
    sc_num_9 = 3;
    sc_type_10 = "pilot";
    sc_type_11 = "data";
    sc_num_11 = 3;
    sc_type_12 = "pilot";

    // guard band nulls
    sc_type_13 = "null";
    sc_num_13 = 4;
}
};

```

// master\_scenario\_file.cfg

```

NumberOfScenarios = 1;
reps_all_scenarios = 1;

scenario_1 = "Tutorial_3";

```

## Chapter 8

# Class Index

### 8.1 Class List

Here are the classes, structs, unions and interfaces with brief descriptions:

<a href="#">Cognitive_Engine</a>	
The base class for the custom cognitive engines built using the ECR (Extensible Cognitive Radio)	25
<a href="#">ExtensibleCognitiveRadio</a>	26
<a href="#">Interferer</a>	32
<a href="#">ExtensibleCognitiveRadio::metric_s</a>	
Contains metric information related to the quality of a received frame. This information is made available to the custom <a href="#">Cognitive_Engine::execute()</a> implementation and is accessed in the instance of this struct: <a href="#">ExtensibleCognitiveRadio::CE_metrics</a>	33
<a href="#">node_parameters</a>	35
<a href="#">ExtensibleCognitiveRadio::rx_parameter_s</a>	
Contains parameters defining how to handle frame reception	36
<a href="#">ExtensibleCognitiveRadio::rx_statistics</a>	38
<a href="#">Scenario_Controller</a>	38
<a href="#">scenario_parameters</a>	39
<a href="#">timer_s</a>	39
<a href="#">ExtensibleCognitiveRadio::tx_parameter_s</a>	
Contains parameters defining how to handle frame transmission	39



## Chapter 9

# Class Documentation

### 9.1 Cognitive\_Engine Class Reference

The base class for the custom cognitive engines built using the ECR (Extensible Cognitive Radio).

```
#include <CE.hpp>
```

#### Public Member Functions

- virtual void `execute` ([ExtensibleCognitiveRadio](#) \*ECR)  
*Executes the custom cognitive engine as defined by the user.*

#### 9.1.1 Detailed Description

The base class for the custom cognitive engines built using the ECR (Extensible Cognitive Radio).

This class is used as the base for the custom (user-defined) cognitive engines (CEs) placed in the `cognitive_engines/` directory of the source tree. The CEs following this model are event-driven: While the radio is running, if certain events occur as defined in `ExtensibleCognitiveRadio::Event`, then the custom-defined `execute` function ([Cognitive\\_Engine::execute\(\)](#)) will be called.

#### 9.1.2 Member Function Documentation

9.1.2.1 void `Cognitive_Engine::execute` ( `ExtensibleCognitiveRadio` \* *ECR* ) [virtual]

Executes the custom cognitive engine as defined by the user.

When writing a custom cognitive engine (CE) using the Extensible Cognitive Radio (ECR), this function should be defined to contain the main processing of the CE. An ECR CE is event-driven: When the radio is running, this [Cognitive\\_Engine::execute\(\)](#) function is called if certain events, as defined in `ExtensibleCognitiveRadio::Event`, occur.

For more information on how to write a custom CE using the ECR, see `TODO:Insert reference here`. Or, for direct examples, refer to the source code of the reimplementations listed below (in the `cognitive_engines/` directory of the source tree).

The documentation for this class was generated from the following files:

- `crts/include/CE.hpp`
- `crts/src/CE.cpp`

## 9.2 ExtensibleCognitiveRadio Class Reference

### Classes

- struct [metric\\_s](#)  
*Contains metric information related to the quality of a received frame. This information is made available to the custom [Cognitive\\_Engine::execute\(\)](#) implementation and is accessed in the instance of this struct: [ExtensibleCognitiveRadio::CE\\_metrics](#).*
- struct [rx\\_parameter\\_s](#)  
*Contains parameters defining how to handle frame reception.*
- struct [rx\\_statistics](#)
- struct [tx\\_parameter\\_s](#)  
*Contains parameters defining how to handle frame transmission.*

### Public Types

- enum [CE\\_Event](#) {  
TIMEOUT = 0, PHY, UHD\_OVERFLOW, UHD\_UNDERRUN,  
USRP\_RX\_SAMPS }  
*Defines the different types of CE events.*
- enum [FrameType](#) { DATA = 0, CONTROL, UNKNOWN }  
*Defines the types of frames used by the ECR.*

### Public Member Functions

- void [set\\_ce](#) (char \*ce)
- void [start\\_ce](#) ()
- void [stop\\_ce](#) ()
- void [set\\_ce\\_timeout\\_ms](#) (double new\_timeout\_ms)  
*Assign a value to [ExtensibleCognitiveRadio::ce\\_timeout\\_ms](#).*
- double [get\\_ce\\_timeout\\_ms](#) ()  
*Get the current value of [ExtensibleCognitiveRadio::ce\\_timeout\\_ms](#).*
- void [set\\_ce\\_sensing](#) (int ce\_sensing)  
*Allows you to turn on/off the USRP\_RX\_SAMPLES events which allow you to perform custom spectrum sensing in the CE while the liquid-ofdm receiver continues to run.*
- void [set\\_ip](#) (char \*ip)  
*Used to set the IP of the ECR's virtual network interface.*
- void [set\\_tx\\_queue\\_len](#) (int queue\_len)  
*Allows you to set the tx buffer length for the virtual network interface This could be useful in trading off between dropped packets and latency with a UDP connection.*
- void [set\\_tx\\_freq](#) (double \_tx\_freq)  
*Set the value of [ExtensibleCognitiveRadio::tx\\_parameter\\_s::tx\\_freq](#).*
- void [set\\_tx\\_freq](#) (double \_tx\_freq, double \_dsp\_freq)
- void [set\\_tx\\_rate](#) (double \_tx\_rate)  
*Set the value of [ExtensibleCognitiveRadio::tx\\_parameter\\_s::tx\\_rate](#).*
- void [set\\_tx\\_gain\\_soft](#) (double \_tx\_gain\_soft)  
*Set the value of [ExtensibleCognitiveRadio::tx\\_parameter\\_s::tx\\_gain\\_soft](#).*
- void [set\\_tx\\_gain\\_uhd](#) (double \_tx\_gain\_uhd)  
*Set the value of [ExtensibleCognitiveRadio::tx\\_parameter\\_s::tx\\_gain\\_uhd](#).*
- void [set\\_tx\\_antenna](#) (char \*\_tx\_antenna)
- void [set\\_tx\\_modulation](#) (int mod\_scheme)  
*Set the value of `mod_scheme` in [ExtensibleCognitiveRadio::tx\\_parameter\\_s::fgprops](#).*



- void [set\\_tx\\_crc](#) (int crc\_scheme)  
Set the value of *check* in [ExtensibleCognitiveRadio::tx\\_parameter\\_s::fgprops](#).
- void [set\\_tx\\_fec0](#) (int fec\_scheme)  
Set the value of *fec0* in [ExtensibleCognitiveRadio::tx\\_parameter\\_s::fgprops](#).
- void [set\\_tx\\_fec1](#) (int fec\_scheme)  
Set the value of *fec1* in [ExtensibleCognitiveRadio::tx\\_parameter\\_s::fgprops](#).
- void [set\\_tx\\_subcarriers](#) (unsigned int subcarriers)  
Set the value of [ExtensibleCognitiveRadio::tx\\_parameter\\_s::numSubcarriers](#).
- void [set\\_tx\\_subcarrier\\_alloc](#) (char \*\_subcarrierAlloc)  
Set [ExtensibleCognitiveRadio::tx\\_parameter\\_s::subcarrierAlloc](#).
- void [set\\_tx\\_cp\\_len](#) (unsigned int cp\_len)  
Set the value of [ExtensibleCognitiveRadio::tx\\_parameter\\_s::cp\\_len](#).
- void [set\\_tx\\_taper\\_len](#) (unsigned int taper\_len)  
Set the value of [ExtensibleCognitiveRadio::tx\\_parameter\\_s::taper\\_len](#).
- void [set\\_tx\\_control\\_info](#) (unsigned char \*\_control\_info)  
Set the control information used for future transmit frames.
- void [set\\_tx\\_payload\\_sym\\_len](#) (unsigned int len)  
Set the number of symbols transmitted in each frame payload. For now since the ECR does not have any segmentation/concatenation capabilities, the actual payload will be an integer number of IP packets, so this value really provides a lower bound for the payload length in symbols.
- void [increase\\_tx\\_mod\\_order](#) ()  
Increases the modulation order if possible.
- void [decrease\\_tx\\_mod\\_order](#) ()  
Decreases the modulation order if possible.
- int [get\\_tx\\_state](#) ()  
Return the value of [ExtensibleCognitiveRadio::tx\\_parameter\\_s::tx\\_state](#).
- double [get\\_tx\\_freq](#) ()  
Return the value of [ExtensibleCognitiveRadio::tx\\_parameter\\_s::tx\\_freq](#).
- double [get\\_tx\\_rate](#) ()  
Return the value of [ExtensibleCognitiveRadio::tx\\_parameter\\_s::tx\\_rate](#).
- double [get\\_tx\\_gain\\_soft](#) ()  
Return the value of [ExtensibleCognitiveRadio::tx\\_parameter\\_s::tx\\_gain\\_soft](#).
- double [get\\_tx\\_gain\\_uhd](#) ()  
Return the value of [ExtensibleCognitiveRadio::tx\\_parameter\\_s::tx\\_gain\\_uhd](#).
- char \* [get\\_tx\\_antenna](#) ()
- int [get\\_tx\\_modulation](#) ()  
Return the value of *mod\_scheme* in [ExtensibleCognitiveRadio::tx\\_parameter\\_s::fgprops](#).
- int [get\\_tx\\_crc](#) ()  
Return the value of *check* in [ExtensibleCognitiveRadio::tx\\_parameter\\_s::fgprops](#).
- int [get\\_tx\\_fec0](#) ()  
Return the value of *fec0* in [ExtensibleCognitiveRadio::tx\\_parameter\\_s::fgprops](#).
- int [get\\_tx\\_fec1](#) ()  
Return the value of *fec1* in [ExtensibleCognitiveRadio::tx\\_parameter\\_s::fgprops](#).
- unsigned int [get\\_tx\\_subcarriers](#) ()  
Return the value of [ExtensibleCognitiveRadio::tx\\_parameter\\_s::numSubcarriers](#).
- void [get\\_tx\\_subcarrier\\_alloc](#) (char \*subcarrierAlloc)  
Get current [ExtensibleCognitiveRadio::tx\\_parameter\\_s::subcarrierAlloc](#).
- unsigned int [get\\_tx\\_cp\\_len](#) ()  
Return the value of [ExtensibleCognitiveRadio::tx\\_parameter\\_s::cp\\_len](#).
- unsigned int [get\\_tx\\_taper\\_len](#) ()
- void [get\\_tx\\_control\\_info](#) (unsigned char \*\_control\_info)

- double **get\_tx\_data\_rate** ()
- void **start\_tx** ()
- void **start\_tx\_for\_frames** (int \_num\_tx\_frames)
- void **stop\_tx** ()
- void **reset\_tx** ()
- void **transmit\_frame** (unsigned char \*\_header, unsigned char \*\_payload, unsigned int \_payload\_len)  
*Transmit a custom frame.*
- void **set\_rx\_freq** (double \_rx\_freq)  
*Set the value of [ExtensibleCognitiveRadio::rx\\_parameter\\_s::rx\\_freq](#).*
- void **set\_rx\_freq** (double \_rx\_freq, double \_dsp\_freq)
- void **set\_rx\_rate** (double \_rx\_rate)  
*Set the value of [ExtensibleCognitiveRadio::rx\\_parameter\\_s::rx\\_rate](#).*
- void **set\_rx\_gain\_uhd** (double \_rx\_gain\_uhd)  
*Set the value of [ExtensibleCognitiveRadio::rx\\_parameter\\_s::rx\\_gain\\_uhd](#).*
- void **set\_rx\_antenna** (char \*\_rx\_antenna)
- void **set\_rx\_subcarriers** (unsigned int subcarriers)  
*Set the value of [ExtensibleCognitiveRadio::rx\\_parameter\\_s::numSubcarriers](#).*
- void **set\_rx\_subcarrier\_alloc** (char \*\_subcarrierAlloc)  
*Set [ExtensibleCognitiveRadio::rx\\_parameter\\_s::subcarrierAlloc](#).*
- void **set\_rx\_cp\_len** (unsigned int cp\_len)  
*Set the value of [ExtensibleCognitiveRadio::rx\\_parameter\\_s::cp\\_len](#).*
- void **set\_rx\_taper\_len** (unsigned int taper\_len)  
*Set the value of [ExtensibleCognitiveRadio::rx\\_parameter\\_s::taper\\_len](#).*
- double **get\_rx\_state** ()  
*Return the value of [ExtensibleCognitiveRadio::rx\\_parameter\\_s::rx\\_state](#).*
- double **get\_rx\_freq** ()  
*Return the value of [ExtensibleCognitiveRadio::rx\\_parameter\\_s::rx\\_freq](#).*
- double **get\_rx\_rate** ()  
*Return the value of [ExtensibleCognitiveRadio::rx\\_parameter\\_s::rx\\_rate](#).*
- double **get\_rx\_gain\_uhd** ()  
*Return the value of [ExtensibleCognitiveRadio::rx\\_parameter\\_s::rx\\_gain\\_uhd](#).*
- char \* **get\_rx\_antenna** ()
- unsigned int **get\_rx\_subcarriers** ()  
*Return the value of [ExtensibleCognitiveRadio::rx\\_parameter\\_s::numSubcarriers](#).*
- void **get\_rx\_subcarrier\_alloc** (char \*subcarrierAlloc)  
*Get current [ExtensibleCognitiveRadio::rx\\_parameter\\_s::subcarrierAlloc](#).*
- unsigned int **get\_rx\_cp\_len** ()  
*Return the value of [ExtensibleCognitiveRadio::rx\\_parameter\\_s::cp\\_len](#).*
- unsigned int **get\_rx\_taper\_len** ()  
*Return the value of [ExtensibleCognitiveRadio::rx\\_parameter\\_s::taper\\_len](#).*
- void **get\_rx\_control\_info** (unsigned char \*\_control\_info)
- void **reset\_rx** ()
- void **start\_rx** ()
- void **stop\_rx** ()
- void **start\_liquid\_rx** ()
- void **stop\_liquid\_rx** ()
- void **set\_rx\_stat\_tracking** (bool state, float sec)
- float **get\_rx\_stat\_tracking\_period** ()
- struct [rx\\_statistics](#) **get\_rx\_stats** ()
- void **print\_metrics** ([ExtensibleCognitiveRadio](#) \*CR)
- void **log\_rx\_metrics** ()
- void **log\_tx\_parameters** ()
- void **reset\_log\_files** ()

## Public Attributes

- struct [metric\\_s](#) **CE\_metrics**  
*The instance of [ExtensibleCognitiveRadio::metric\\_s](#) made accessible to the [Cognitive\\_Engine](#).*
- `std::complex< float > * ce_usrp_rx_buffer`  
*USRP samples will be written to this buffer if the `ce_sensing_flag` is set.*
- int [ce\\_usrp\\_rx\\_buffer\\_length](#)  
*Length of the buffer for USRP samples.*
- int **print\_metrics\_flag**
- int **log\_phy\_rx\_flag**
- int **log\_phy\_tx\_flag**
- char **phy\_rx\_log\_file** [100]
- char **phy\_tx\_log\_file** [100]
- `std::ofstream log_rx_fstream`
- `std::ofstream log_tx_fstream`
- `uhd::usrp::multi_usrp::sptr usrp_tx`
- `uhd::tx_metadata_t metadata_tx`
- `uhd::usrp::multi_usrp::sptr usrp_rx`
- `uhd::rx_metadata_t metadata_rx`

## Private Member Functions

- void **update\_rx\_stats** ()
- void **update\_rx\_params** ()
- void **update\_tx\_params** ()

## Private Attributes

- [Cognitive\\_Engine](#) \* **CE**
- double [ce\\_timeout\\_ms](#)  
*The maximum length of time to go without an event before executing the CE under a timeout event. In milliseconds.*
- bool **ce\_phy\_events**
- int **ce\_sensing\_flag**
- `pthread_t CE_process`
- `pthread_mutex_t CE_mutex`
- `pthread_mutex_t CE_fftw_mutex`
- `pthread_cond_t CE_cond`
- `pthread_cond_t CE_execute_sig`
- bool **ce\_thread\_running**
- bool **ce\_running**
- struct [rx\\_statistics](#) **rx\_stats**
- bool **rx\_stat\_tracking**
- float **rx\_stat\_tracking\_period**
- int **tunfd**
- char **tun\_name** [IFNAMSIZ]
- char **systemCMD** [200]
- struct [rx\\_parameter\\_s](#) **rx\_params**
- int **update\_rx\_flag**
- int **update\_usrp\_rx**
- int **recreate\_fs**
- `ofdmflexframesync fs`
- unsigned int **frame\_num**
- `pthread_t rx_process`

- pthread\_mutex\_t **rx\_mutex**
- pthread\_cond\_t **rx\_cond**
- int **rx\_state**
- bool **rx\_thread\_running**
- [tx\\_parameter\\_s](#) **tx\_params**
- [tx\\_parameter\\_s](#) **tx\_params\_updated**
- int **update\_tx\_flag**
- int **update\_usrp\_tx**
- int **recreate\_fg**
- ofdmflexframegen **fg**
- unsigned int **fgbuffer\_len**
- std::complex< float > \* **fgbuffer**
- unsigned char **tx\_header** [8]
- unsigned int **frame\_counter**
- unsigned int **numDataSubcarriers**
- double **tx\_data\_rate**
- int **update\_tx\_data\_rate**
- int **num\_tx\_frames**
- pthread\_t **tx\_process**
- pthread\_mutex\_t **tx\_mutex**
- pthread\_cond\_t **tx\_cond**
- bool **tx\_thread\_running**
- int **tx\_state**

### Static Private Attributes

- static int **uhd\_msg**

### Friends

- void \* **ECR\_ce\_worker** (void \*)
- void **uhd\_msg\_handler** (uhd::msg::type\_t type, const std::string &msg)
- void \* **ECR\_rx\_worker** (void \*)
- int **rxCallback** (unsigned char \*, int, unsigned char \*, unsigned int, int, framesyncstats\_s, void \*)
- void \* **ECR\_tx\_worker** (void \*)

## 9.2.1 Member Enumeration Documentation

### 9.2.1.1 enum ExtensibleCognitiveRadio::CE\_Event

Defines the different types of CE events.

The different circumstances under which the CE can be executed are defined here.

#### Enumerator

**TIMEOUT** The CE had not been executed for a period of time as defined by [ExtensibleCognitiveRadio::ce\\_timeout\\_ms](#). It is now executed as a timeout event.

**PHY** A PHY layer event has caused the execution of the CE. Usually this means a frame was received by the radio.

**UHD\_OVERFLOW** The receiver processing is not able to keep up with the current settings.

**UHD\_UNDERRUN** The transmitter is not providing samples fast enough the the USRP.

**USRP\_RX\_SAMPS** This event enables the design of custom spectrum sensing which can be employed without interrupting the normal reception of frames.

### 9.2.1.2 enum ExtensibleCognitiveRadio::FrameType

Defines the types of frames used by the ECR.

#### Enumerator

**DATA** The frame contains application layer data. Data frames contain IP packets that are read from the virtual network interface and subsequently transmitted over the air.

**CONTROL** The frame was sent explicitly at the behest of another cognitive engine (CE) in the network and it contains custom data for use by the receiving CE. The handling of [ExtensibleCognitiveRadio::DATA](#) frames is performed automatically by the Extensible Cognitive Radio (ECR). However, the CE may initiate the transmission of a custom control frame containing information to be relayed to another CE in the network. A custom frame can be sent using [ExtensibleCognitiveRadio::transmit\\_frame\(\)](#).

**UNKNOWN** The Extensible Cognitive Radio (ECR) is unable to determine the type of the received frame. The received frame was too corrupted to determine its type.

## 9.2.2 Member Function Documentation

### 9.2.2.1 void ExtensibleCognitiveRadio::get\_rx\_subcarrier\_alloc ( char \* subcarrierAlloc )

Get current [ExtensibleCognitiveRadio::rx\\_parameter\\_s::subcarrierAlloc](#).

`subcarrierAlloc` should be a pointer to an array of size [ExtensibleCognitiveRadio::rx\\_parameter\\_s::num-Subcarriers](#). The array will then be filled with the current subcarrier allocation.

### 9.2.2.2 void ExtensibleCognitiveRadio::get\_tx\_subcarrier\_alloc ( char \* subcarrierAlloc )

Get current [ExtensibleCognitiveRadio::tx\\_parameter\\_s::subcarrierAlloc](#).

`subcarrierAlloc` should be a pointer to an array of size [ExtensibleCognitiveRadio::tx\\_parameter\\_s::num-Subcarriers](#). The array will then be filled with the current subcarrier allocation.

### 9.2.2.3 unsigned int ExtensibleCognitiveRadio::get\_tx\_taper\_len ( )

Return the value of [ExtensibleCognitiveRadio::tx\\_parameter\\_s::taper\\_len](#).

### 9.2.2.4 void ExtensibleCognitiveRadio::transmit\_frame ( unsigned char \* \_header, unsigned char \* \_payload, unsigned int \_payload\_len )

Transmit a custom frame.

The cognitive engine (CE) can initiate transmission of a custom frame by calling this function. `_header` must be a pointer to an array of exactly 8 elements of type `unsigned int`. The first byte of `_header` **must** be set to [ExtensibleCognitiveRadio::CONTROL](#). For Example:

```
ExtensibleCognitiveRadio ECR;
unsigned char myHeader[8];
unsigned char myPayload[20];
myHeader[0] = ExtensibleCognitiveRadio::CONTROL.
ECR.transmit_frame(myHeader, myPayload, 20);
```

`_payload` is an array of `unsigned char` and can be any length. It can contain any data as would be useful to the CE.

`_payload_len` is the number of elements in `_payload`.

### 9.2.3 Member Data Documentation

#### 9.2.3.1 `double ExtensibleCognitiveRadio::ce_timeout_ms` [private]

The maximum length of time to go without an event before executing the CE under a timeout event. In milliseconds.

The CE is executed every time an event occurs. The CE can also be executed if no event has occurred after some period of time. This is referred to as a timeout event and this variable defines the length of the timeout period in milliseconds.

It can be accessed using [ExtensibleCognitiveRadio::set\\_ce\\_timeout\\_ms\(\)](#) and [ExtensibleCognitiveRadio::get\\_ce\\_timeout\\_ms\(\)](#).

The documentation for this class was generated from the following files:

- `crts/include/ECR.hpp`
- `crts/src/ECR.cpp`

## 9.3 Interferer Class Reference

### Public Member Functions

- void **start\_tx** ()
- void **stop\_tx** ()
- void **set\_log\_file** (char \*)
- void **log\_tx\_parameters** ()
- void **UpdateFrequency** ()
- void **TransmitInterference** ()
- void **BuildCWTransmission** ()
- void **BuildNOISETransmission** ()
- void **BuildGMSKTransmission** ()
- void **BuildRRCTransmission** ()
- void **BuildOFDMTransmission** ()

### Public Attributes

- int **interference\_type**
- double **tx\_gain\_soft**
- double **tx\_gain**
- double **tx\_freq**
- double **tx\_rate**
- double **period**
- double **duty\_cycle**
- int **tx\_freq\_behavior**
- double **tx\_freq\_min**
- double **tx\_freq\_max**
- double **tx\_freq\_bandwidth**
- double **tx\_freq\_dwell\_time**
- double **tx\_freq\_resolution**
- [timer](#) **duty\_cycle\_timer**
- [timer](#) **freq\_dwell\_timer**
- bool **log\_tx\_flag**
- `std::ofstream` **tx\_log\_file**
- char **tx\_log\_file\_name** [100]
- `resamp2_crcf` **interp**

- gmskframegen **gmsk\_fg**
- firfilt\_crcf **rrc\_filt**
- ofdmflexframegenprops\_s **fgprops**
- ofdmflexframegen **ofdm\_fg**
- uhd::usrp::multi\_usrp::sptr **usrp\_tx**
- uhd::tx\_metadata\_t **metadata\_tx**
- unsigned int **buffered\_samps**
- std::vector< std::complex  
< float > > **tx\_buffer**
- pthread\_t **tx\_process**
- pthread\_mutex\_t **tx\_mutex**
- pthread\_cond\_t **tx\_cond**
- bool **tx\_running**
- bool **tx\_thread\_running**
- int **tx\_state**

## Friends

- void \* **Interferer\_tx\_worker** (void \*)

The documentation for this class was generated from the following files:

- crts/include/interferer.hpp
- crts/src/interferer.cpp

## 9.4 ExtensibleCognitiveRadio::metric\_s Struct Reference

Contains metric information related to the quality of a received frame. This information is made available to the custom [Cognitive\\_Engine::execute\(\)](#) implementation and is accessed in the instance of this struct: [ExtensibleCognitiveRadio::CE\\_metrics](#).

```
#include <ECR.hpp>
```

## Public Attributes

- [ExtensibleCognitiveRadio::CE\\_Event](#) **CE\_event**  
*Specifies the circumstances under which the CE was executed.*
- [ExtensibleCognitiveRadio::FrameType](#) **CE\_frame**  
*Specifies the type of frame received as defined by [ExtensibleCognitiveRadio::FrameType](#).*
- int **control\_valid**  
*Indicates whether the `control` information of the received frame passed error checking tests.*
- unsigned char **control\_info** [6]  
*The control info of the received frame.*
- unsigned char \* **payload**  
*The payload data of the received frame.*
- int **payload\_valid**  
*Indicates whether the `payload` of the received frame passed error checking tests.*
- unsigned int **payload\_len**  
*The number of elements of the `payload` array.*
- unsigned int **frame\_num**  
*The frame number of the received [ExtensibleCognitiveRadio::DATA](#) frame.*
- framesyncstats\_s **stats**

The statistics of the received frame as reported by `liquid-dsp`.

- `uhd::time_spec_t time_spec`

The `uhd::time_spec_t` object returned by the UHD driver upon reception of a complete frame.

### 9.4.1 Detailed Description

Contains metric information related to the quality of a received frame. This information is made available to the custom `Cognitive_Engine::execute()` implementation and is accessed in the instance of this struct: `ExtensibleCognitiveRadio::CE_metrics`.

The members of this struct will be valid when a frame has been received which will be indicated when the `ExtensibleCognitiveRadio::metric_s.CE_event == PHY`. Otherwise, they will represent results from previous frames.

The valid members under a `ExtensibleCognitiveRadio::PHY` event are:

`ExtensibleCognitiveRadio::metric_s::CE_frame`,  
`ExtensibleCognitiveRadio::metric_s::control_valid`,  
`ExtensibleCognitiveRadio::metric_s::control_info`,  
`ExtensibleCognitiveRadio::metric_s::payload`,  
`ExtensibleCognitiveRadio::metric_s::payload_valid`,  
`ExtensibleCognitiveRadio::metric_s::payload_len`,  
`ExtensibleCognitiveRadio::metric_s::frame_num`,  
`ExtensibleCognitiveRadio::metric_s::stats`, and  
`ExtensibleCognitiveRadio::metric_s::time_spec`

### 9.4.2 Member Data Documentation

#### 9.4.2.1 `ExtensibleCognitiveRadio::CE_Event` `ExtensibleCognitiveRadio::metric_s::CE_event`

Specifies the circumstances under which the CE was executed.

When the CE is executed, this value is set according to the type of event that caused the CE execution, as specified in `ExtensibleCognitiveRadio::Event`.

#### 9.4.2.2 `int ExtensibleCognitiveRadio::metric_s::control_valid`

Indicates whether the `control` information of the received frame passed error checking tests.

Derived from `liquid-dsp`. See the [Liquid Documentation](#) for more information.

#### 9.4.2.3 `unsigned int ExtensibleCognitiveRadio::metric_s::frame_num`

The frame number of the received `ExtensibleCognitiveRadio::DATA` frame.

Each `ExtensibleCognitiveRadio::DATA` frame transmitted by the ECR is assigned a number, according to the order in which it was transmitted.

#### 9.4.2.4 `unsigned int ExtensibleCognitiveRadio::metric_s::payload_len`

The number of elements of the `payload` array.

Equal to the byte length of the `payload`.



## 9.4.2.5 int ExtensibleCognitiveRadio::metric\_s::payload\_valid

Indicates whether the `payload` of the received frame passed error checking tests.

Derived from `liquid-dsp`. See the [Liquid Documentation](#) for more information.

## 9.4.2.6 framesyncstats\_s ExtensibleCognitiveRadio::metric\_s::stats

The statistics of the received frame as reported by `liquid-dsp`.

For information about its members, refer to the [Liquid Documentation](#).

## 9.4.2.7 uhd::time\_spec\_t ExtensibleCognitiveRadio::metric\_s::time\_spec

The `uhd::time_spec_t` object returned by the `UHD` driver upon reception of a complete frame.

This serves as a marker to denote at what time the end of the frame was received.

The documentation for this struct was generated from the following file:

- `crts/include/ECR.hpp`

## 9.5 node\_parameters Struct Reference

### Public Attributes

- int **type**
- int **cr\_type**
- char **python\_file** [100]
- char **arguments** [20][50]
- int **num\_arguments**
- char **CORNET\_IP** [20]
- char **CRTS\_IP** [20]
- char **TARGET\_IP** [20]
- int **net\_traffic\_type**
- int **net\_burst\_length**
- double **net\_mean\_throughput**
- char **CE** [100]
- double **ce\_timeout\_ms**
- int **print\_metrics**
- int **log\_phy\_rx**
- int **log\_phy\_tx**
- int **log\_net\_rx**
- int **log\_net\_tx**
- char **phy\_rx\_log\_file** [100]
- char **phy\_tx\_log\_file** [100]
- char **net\_rx\_log\_file** [100]
- char **net\_tx\_log\_file** [100]
- int **generate\_octave\_logs**
- int **generate\_python\_logs**
- double **rx\_freq**
- double **rx\_rate**
- double **rx\_gain**
- double **tx\_freq**
- double **tx\_rate**

- double **tx\_gain**
- int **duplex**
- int **rx\_subcarriers**
- int **rx\_cp\_len**
- int **rx\_taper\_len**
- int **rx\_subcarrier\_alloc\_method**
- int **rx\_guard\_subcarriers**
- int **rx\_central\_nulls**
- int **rx\_pilot\_freq**
- char **rx\_subcarrier\_alloc** [2048]
- double **tx\_gain\_soft**
- int **tx\_subcarriers**
- int **tx\_cp\_len**
- int **tx\_taper\_len**
- int **tx\_modulation**
- int **tx\_crc**
- int **tx\_fec0**
- int **tx\_fec1**
- int **tx\_subcarrier\_alloc\_method**
- int **tx\_guard\_subcarriers**
- int **tx\_central\_nulls**
- int **tx\_pilot\_freq**
- char **tx\_subcarrier\_alloc** [2048]
- int **interference\_type**
- double **period**
- double **duty\_cycle**
- int **tx\_freq\_behavior**
- double **tx\_freq\_min**
- double **tx\_freq\_max**
- double **tx\_freq\_dwell\_time**
- double **tx\_freq\_resolution**

The documentation for this struct was generated from the following file:

- `crts/include/node_parameters.hpp`

## 9.6 ExtensibleCognitiveRadio::rx\_parameter\_s Struct Reference

Contains parameters defining how to handle frame reception.

```
#include <ECR.hpp>
```

### Public Attributes

- unsigned int **numSubcarriers**  
*The number of subcarriers in the OFDM waveform generated by `liquid`.*
- unsigned int **cp\_len**  
*The length of the cyclic prefix in the OFDM waveform generator from `liquid`.*
- unsigned int **taper\_len**  
*The overlapping taper length in the OFDM waveform generator from `liquid`.*
- unsigned char \* **subcarrierAlloc**  
*An array of `unsigned char` whose number of elements is `ExtensibleCognitiveRadio::tx_parameter_s::numSubcarriers`. Each element in the array should define that subcarrier's allocation.*

- double [rx\\_gain\\_uhd](#)  
*The value of the hardware gain for the receiver. In dB.*
- double [rx\\_freq](#)  
*The receiver local oscillator frequency in Hertz.*
- double [rx\\_dsp\\_freq](#)  
*The transmitter NCO frequency in Hertz.*
- double [rx\\_rate](#)  
*The sample rate of the receiver in samples/second.*

### 9.6.1 Detailed Description

Contains parameters defining how to handle frame reception.

The member parameters are accessed using the instance of the struct: `ExtensibleCognitiveRadio::tx_params`.

Note that for frames to be received successfully These settings must match the corresponding settings at the transmitter.

### 9.6.2 Member Data Documentation

#### 9.6.2.1 unsigned int ExtensibleCognitiveRadio::rx\_parameter\_s::cp\_len

The length of the cyclic prefix in the OFDM waveform generator from [liquid](#).

See the [OFDM Framing Tutorial](#) for details.

#### 9.6.2.2 unsigned int ExtensibleCognitiveRadio::rx\_parameter\_s::numSubcarriers

The number of subcarriers in the OFDM waveform generated by [liquid](#).

See the [OFDM Framing Tutorial](#) for details.

#### 9.6.2.3 double ExtensibleCognitiveRadio::rx\_parameter\_s::rx\_dsp\_freq

The transmitter NCO frequency in Hertz.

The USRP has an NCO which can be used to digitally mix the signal anywhere within the baseband bandwidth of the USRP daughterboard. This can be useful for offsetting the tone resulting from LO leakage of the ZIF receiver used by the USRP.

#### 9.6.2.4 double ExtensibleCognitiveRadio::rx\_parameter\_s::rx\_freq

The receiver local oscillator frequency in Hertz.

It can be accessed with [ExtensibleCognitiveRadio::set\\_rx\\_freq\(\)](#) and [ExtensibleCognitiveRadio::get\\_rx\\_freq\(\)](#).

This value is passed directly to [UHD](#).

#### 9.6.2.5 double ExtensibleCognitiveRadio::rx\_parameter\_s::rx\_gain\_uhd

The value of the hardware gain for the receiver. In dB.

Sets the gain of the hardware amplifier in the receive chain of the USRP. This value is passed directly to [UHD](#).

It can be accessed with [ExtensibleCognitiveRadio::set\\_rx\\_gain\\_uhd\(\)](#) and [ExtensibleCognitiveRadio::get\\_rx\\_gain\\_uhd\(\)](#).

Run

\$ uhd\_usrp\_probe

for details about the particular gain limits of your USRP device.

#### 9.6.2.6 double ExtensibleCognitiveRadio::rx\_parameter\_s::rx\_rate

The sample rate of the receiver in samples/second.

It can be accessed with [ExtensibleCognitiveRadio::set\\_rx\\_rate\(\)](#) and [ExtensibleCognitiveRadio::get\\_rx\\_rate\(\)](#).

This value is passed directly to [UHD](#).

#### 9.6.2.7 unsigned char\* ExtensibleCognitiveRadio::rx\_parameter\_s::subcarrierAlloc

An array of `unsigned char` whose number of elements is [ExtensibleCognitiveRadio::tx\\_parameter\\_s::num-Subcarriers](#). Each element in the array should define that subcarrier's allocation.

A subcarrier's allocation defines it as a null subcarrier, a pilot subcarrier, or a data subcarrier.

See [Subcarrier Allocation](#) in the [liquid](#) documentation for details.

Also refer to the [OFDM Framing Tutorial](#) for more information.

#### 9.6.2.8 unsigned int ExtensibleCognitiveRadio::rx\_parameter\_s::taper\_len

The overlapping taper length in the OFDM waveform generator from [liquid](#).

See the [OFDM Framing Tutorial](#) and the [Liquid Documentation Reference](#) for details.

The documentation for this struct was generated from the following file:

- `crts/include/ECR.hpp`

## 9.7 ExtensibleCognitiveRadio::rx\_statistics Struct Reference

### Public Attributes

- `int frames_received`
- `float avg_evm`
- `float avg_rssi`
- `float avg_per`
- `float avg_throughput`

The documentation for this struct was generated from the following file:

- `crts/include/ECR.hpp`

## 9.8 Scenario\_Controller Class Reference

### Public Member Functions

- `virtual void execute (int node, char fb_type, void *_arg)`
- `virtual void initialize_node_fb ()`
- `void set_node_parameter (int node, char cont_type, void *_arg)`

### Public Attributes

- int \* **TCP\_nodes**
- struct [scenario\\_parameters](#) **sp**
- struct [node\\_parameters](#) **np** [48]

The documentation for this class was generated from the following files:

- crts/include/SC.hpp
- crts/src/SC.cpp

## 9.9 scenario\_parameters Struct Reference

### Public Attributes

- int **num\_nodes**
- time\_t **start\_time\_s**
- time\_t **runTime**
- unsigned int **totalNumReps**
- unsigned int **repNumber**
- char **SC** [100]

The documentation for this struct was generated from the following file:

- crts/include/read\_configs.hpp

## 9.10 timer\_s Struct Reference

### Public Attributes

- struct timeval **tic**
- struct timeval **toc**
- int **timer\_started**

The documentation for this struct was generated from the following file:

- crts/src/timer.cc

## 9.11 ExtensibleCognitiveRadio::tx\_parameter\_s Struct Reference

Contains parameters defining how to handle frame transmission.

```
#include <ECR.hpp>
```

### Public Attributes

- unsigned int [numSubcarriers](#)  
*The number of subcarriers in the OFDM waveform generated by [liquid](#).*
- unsigned int [cp\\_len](#)  
*The length of the cyclic prefix in the OFDM waveform generator from [liquid](#).*
- unsigned int [taper\\_len](#)

- The overlapping taper length in the OFDM waveform generator from [liquid](#).
- unsigned char \* [subcarrierAlloc](#)

An array of `unsigned char` whose number of elements is [ExtensibleCognitiveRadio::tx\\_parameter\\_s::numSubcarriers](#). Each element in the array should define that subcarrier's allocation.
- ofdmflexframegenprops\_s [fgprops](#)

The properties for the OFDM frame generator from [liquid](#).
- double [tx\\_gain\\_uhd](#)

The value of the hardware gain for the transmitter. In dB.
- double [tx\\_gain\\_soft](#)

The software gain of the transmitter. In dB.
- double [tx\\_freq](#)

The transmitter local oscillator frequency in Hertz.
- double [tx\\_dsp\\_freq](#)

The transmitter NCO frequency in Hertz.
- double [tx\\_rate](#)

The sample rate of the transmitter in samples/second.
- unsigned int [payload\\_sym\\_length](#)

### 9.11.1 Detailed Description

Contains parameters defining how to handle frame transmission.

The member parameters are accessed using the instance of the struct: `ExtensibleCognitiveRadio::tx_params`.

Note that for frames to be received successfully These settings must match the corresponding settings at the receiver.

### 9.11.2 Member Data Documentation

#### 9.11.2.1 unsigned int ExtensibleCognitiveRadio::tx\_parameter\_s::cp\_len

The length of the cyclic prefix in the OFDM waveform generator from [liquid](#).

See the [OFDM Framing Tutorial](#) for details.

#### 9.11.2.2 ofdmflexframegenprops\_s ExtensibleCognitiveRadio::tx\_parameter\_s::fgprops

The properties for the OFDM frame generator from [liquid](#).

See the [Liquid Documentation](#) for details.

Members of this struct can be accessed with the following functions:

- `check:`
  - [ExtensibleCognitiveRadio::set\\_tx\\_crc\(\)](#)
  - [ExtensibleCognitiveRadio::get\\_tx\\_crc\(\)](#).
- `fec0:`
  - [ExtensibleCognitiveRadio::set\\_tx\\_fec0\(\)](#)
  - [ExtensibleCognitiveRadio::get\\_tx\\_fec0\(\)](#).
- `fec1:`
  - [ExtensibleCognitiveRadio::set\\_tx\\_fec1\(\)](#)
  - [ExtensibleCognitiveRadio::get\\_tx\\_fec1\(\)](#).

- `mod_scheme`:
  - [ExtensibleCognitiveRadio::set\\_tx\\_modulation\(\)](#)
  - [ExtensibleCognitiveRadio::get\\_tx\\_modulation\(\)](#).

#### 9.11.2.3 unsigned int ExtensibleCognitiveRadio::tx\_parameter\_s::numSubcarriers

The number of subcarriers in the OFDM waveform generated by [liquid](#).

See the [OFDM Framing Tutorial](#) for details.

#### 9.11.2.4 unsigned char\* ExtensibleCognitiveRadio::tx\_parameter\_s::subcarrierAlloc

An array of `unsigned char` whose number of elements is [ExtensibleCognitiveRadio::tx\\_parameter\\_s::numSubcarriers](#). Each element in the array should define that subcarrier's allocation.

A subcarrier's allocation defines it as a null subcarrier, a pilot subcarrier, or a data subcarrier.

See [Subcarrier Allocation](#) in the [liquid](#) documentation for details.

Also refer to the [OFDM Framing Tutorial](#) for more information.

#### 9.11.2.5 unsigned int ExtensibleCognitiveRadio::tx\_parameter\_s::taper\_len

The overlapping taper length in the OFDM waveform generator from [liquid](#).

See the [OFDM Framing Tutorial](#) and the [Liquid Documentation Reference](#) for details.

#### 9.11.2.6 double ExtensibleCognitiveRadio::tx\_parameter\_s::tx\_dsp\_freq

The transmitter NCO frequency in Hertz.

The USRP has an NCO which can be used to digitally mix the signal anywhere within the baseband bandwidth of the USRP daughterboard. This can be useful for offsetting the tone resulting from LO leakage of the ZIF transmitter used by the USRP.

#### 9.11.2.7 double ExtensibleCognitiveRadio::tx\_parameter\_s::tx\_freq

The transmitter local oscillator frequency in Hertz.

It can be accessed with [ExtensibleCognitiveRadio::set\\_tx\\_freq\(\)](#) and [ExtensibleCognitiveRadio::get\\_tx\\_freq\(\)](#).

This value is passed directly to [UHD](#).

#### 9.11.2.8 double ExtensibleCognitiveRadio::tx\_parameter\_s::tx\_gain\_soft

The software gain of the transmitter. In dB.

In addition to the hardware gain ([ExtensibleCognitiveRadio::tx\\_parameter\\_s::tx\\_gain\\_uhd](#)), the gain of the transmission can be adjusted in software by setting this parameter. It is converted to a linear factor and then applied to the frame samples before they are sent to [UHD](#).

It can be accessed with [ExtensibleCognitiveRadio::set\\_tx\\_gain\\_soft\(\)](#) and [ExtensibleCognitiveRadio::get\\_tx\\_gain\\_soft\(\)](#).

Note that the values of samples sent to [UHD](#) must be between -1 and 1. Typically this value is set to around -12 dB based on the peak- to-average power ratio of OFDM signals. Allowing some slight clipping can improve overall signal power at the expense of added distortion.

#### 9.11.2.9 `double ExtensibleCognitiveRadio::tx_parameter_s::tx_gain_uhd`

The value of the hardware gain for the transmitter. In dB.

Sets the gain of the hardware amplifier in the transmit chain of the USRP. This value is passed directly to [UHD](#).

It can be accessed with [ExtensibleCognitiveRadio::set\\_tx\\_gain\\_uhd\(\)](#) and [ExtensibleCognitiveRadio::get\\_tx\\_gain\\_uhd\(\)](#).

Run

```
$ uhd_usrp_probe
```

for details about the particular gain limits of your USRP device.

#### 9.11.2.10 `double ExtensibleCognitiveRadio::tx_parameter_s::tx_rate`

The sample rate of the transmitter in samples/second.

It can be accessed with [ExtensibleCognitiveRadio::set\\_tx\\_rate\(\)](#) and [ExtensibleCognitiveRadio::get\\_tx\\_rate\(\)](#).

This value is passed directly to [UHD](#).

The documentation for this struct was generated from the following file:

- `crts/include/ECR.hpp`



# Index

## CONTROL

ExtensibleCognitiveRadio, [31](#)

## CE\_Event

ExtensibleCognitiveRadio, [30](#)

## CE\_event

ExtensibleCognitiveRadio::metric\_s, [34](#)

## ce\_timeout\_ms

ExtensibleCognitiveRadio, [32](#)

## Cognitive\_Engine, [25](#)

execute, [25](#)

## control\_valid

ExtensibleCognitiveRadio::metric\_s, [34](#)

## cp\_len

ExtensibleCognitiveRadio::rx\_parameter\_s, [37](#)

ExtensibleCognitiveRadio::tx\_parameter\_s, [40](#)

## DATA

ExtensibleCognitiveRadio, [31](#)

## execute

Cognitive\_Engine, [25](#)

## ExtensibleCognitiveRadio

CONTROL, [31](#)

DATA, [31](#)

PHY, [30](#)

TIMEOUT, [30](#)

UHD\_OVERFLOW, [30](#)

UHD\_UNDERRUN, [30](#)

UNKNOWN, [31](#)

USRP\_RX\_SAMPS, [30](#)

## ExtensibleCognitiveRadio, [26](#)

CE\_Event, [30](#)

ce\_timeout\_ms, [32](#)

FrameType, [30](#)

get\_rx\_subcarrier\_alloc, [31](#)

get\_tx\_subcarrier\_alloc, [31](#)

get\_tx\_taper\_len, [31](#)

transmit\_frame, [31](#)

## ExtensibleCognitiveRadio::metric\_s, [33](#)

CE\_event, [34](#)

control\_valid, [34](#)

frame\_num, [34](#)

payload\_len, [34](#)

payload\_valid, [34](#)

stats, [35](#)

time\_spec, [35](#)

## ExtensibleCognitiveRadio::rx\_parameter\_s, [36](#)

cp\_len, [37](#)

numSubcarriers, [37](#)

rx\_dsp\_freq, [37](#)

rx\_freq, [37](#)

rx\_gain\_uhd, [37](#)

rx\_rate, [38](#)

subcarrierAlloc, [38](#)

taper\_len, [38](#)

ExtensibleCognitiveRadio::rx\_statistics, [38](#)

ExtensibleCognitiveRadio::tx\_parameter\_s, [39](#)

cp\_len, [40](#)

fgprops, [40](#)

numSubcarriers, [41](#)

subcarrierAlloc, [41](#)

taper\_len, [41](#)

tx\_dsp\_freq, [41](#)

tx\_freq, [41](#)

tx\_gain\_soft, [41](#)

tx\_gain\_uhd, [41](#)

tx\_rate, [42](#)

## fgprops

ExtensibleCognitiveRadio::tx\_parameter\_s, [40](#)

## frame\_num

ExtensibleCognitiveRadio::metric\_s, [34](#)

## FrameType

ExtensibleCognitiveRadio, [30](#)

## get\_rx\_subcarrier\_alloc

ExtensibleCognitiveRadio, [31](#)

## get\_tx\_subcarrier\_alloc

ExtensibleCognitiveRadio, [31](#)

## get\_tx\_taper\_len

ExtensibleCognitiveRadio, [31](#)

## Interferer, [32](#)

## node\_parameters, [35](#)

## numSubcarriers

ExtensibleCognitiveRadio::rx\_parameter\_s, [37](#)

ExtensibleCognitiveRadio::tx\_parameter\_s, [41](#)

## PHY

ExtensibleCognitiveRadio, [30](#)

## payload\_len

ExtensibleCognitiveRadio::metric\_s, [34](#)

## payload\_valid

ExtensibleCognitiveRadio::metric\_s, [34](#)

## rx\_dsp\_freq

ExtensibleCognitiveRadio::rx\_parameter\_s, [37](#)

## rx\_freq

ExtensibleCognitiveRadio::rx\_parameter\_s, [37](#)

## rx\_gain\_uhd

- ExtensibleCognitiveRadio::rx\_parameter\_s, [37](#)
- rx\_rate
  - ExtensibleCognitiveRadio::rx\_parameter\_s, [38](#)
- Scenario\_Controller, [38](#)
- scenario\_parameters, [39](#)
- stats
  - ExtensibleCognitiveRadio::metric\_s, [35](#)
- subcarrierAlloc
  - ExtensibleCognitiveRadio::rx\_parameter\_s, [38](#)
  - ExtensibleCognitiveRadio::tx\_parameter\_s, [41](#)
- TIMEOUT
  - ExtensibleCognitiveRadio, [30](#)
- taper\_len
  - ExtensibleCognitiveRadio::rx\_parameter\_s, [38](#)
  - ExtensibleCognitiveRadio::tx\_parameter\_s, [41](#)
- time\_spec
  - ExtensibleCognitiveRadio::metric\_s, [35](#)
- timer\_s, [39](#)
- transmit\_frame
  - ExtensibleCognitiveRadio, [31](#)
- tx\_dsp\_freq
  - ExtensibleCognitiveRadio::tx\_parameter\_s, [41](#)
- tx\_freq
  - ExtensibleCognitiveRadio::tx\_parameter\_s, [41](#)
- tx\_gain\_soft
  - ExtensibleCognitiveRadio::tx\_parameter\_s, [41](#)
- tx\_gain\_uhd
  - ExtensibleCognitiveRadio::tx\_parameter\_s, [41](#)
- tx\_rate
  - ExtensibleCognitiveRadio::tx\_parameter\_s, [42](#)
- UHD\_OVERFLOW
  - ExtensibleCognitiveRadio, [30](#)
- UHD\_UNDERRUN
  - ExtensibleCognitiveRadio, [30](#)
- UNKNOWN
  - ExtensibleCognitiveRadio, [31](#)
- USRP\_RX\_SAMPS
  - ExtensibleCognitiveRadio, [30](#)