

Implementation of Cognitive Radio in SEAMCAT

1 Introduction

With spectrum sensing, the interfering devices (i.e. It) try to detect the presence of protected services (i.e. the Wt) in each of the potentially available channels. Spectrum sensing essentially involves conducting a measurement within a candidate channel, to determine whether any protected service is present and transmitting. When a channel is determined to be vacant, sensing is typically applied to adjacent channels to determine what constraints there might be on transmission power, if any.

A key parameter for spectrum sensing is the detection threshold that is used by a cognitive device to detect the presence or the absence of a protected service's transmission. If it detects no emission above this threshold, the WSD (White Space Device) is allowed to transmit, otherwise the WSD keeps silent.

The proposed algorithm in section 3 is designed for a multiple cognitive radio systems. The number of WSD (*numberofWSD*) may be defined by the SEAMCAT user as Active users (in the interfering window dialog) or/and as add/duplicate function as it is done normally when interferers are defined in SEAMCAT.

The main difference in the CR feature compare to what SEAMCAT performs is:

- Detection threshold
- Selection of the operating frequency of the WSD

Note: The implementation only considers traditional vs traditional. The CDMA and the OFDMA LTE module will be disabled when the CR module is activated.

2 Scenario

In SEAMCAT, the interference scenario considers 3 different received signals. These signals are illustrated in Figure 2 and defined as follows:

- **dRSS (: desired Received Signal Strength)** represents the signal transmitted by the Wanted Transmitter (from Wt) to the Victim Receiver (Vr). This is the signal which will experience impairment due to the interferer. For instance it may be a DTT (Digital Terrestrial Television) system.
- **iRSS (: interfering Received Signal Strength)** represents the signal transmitted by the Interfering Transmitter (It) and received by the Victim Receiver (Vr). This is the signal which will impair the dRSS. Here, the It acts as a transmitting device.
- **sRSS (: sensing Received Signal Strength) (new)** represents the signal which is transmitted by the Wt and is sensed by the It. Note that the It acts as a transceiver, meaning that when the energy is "sensed" though the bandwidth of the sensing device (i.e. It), it is acting as a receiving device.

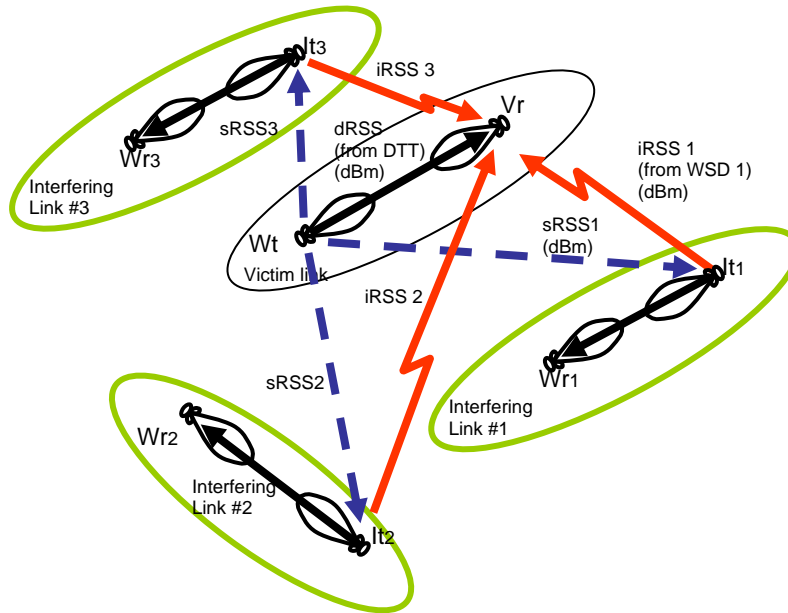


Figure 1: Illustration of 3 cognitive radio systems (WSD) and a victim system

The dRSS and the iRSS already exists in SEAMCAT, therefore it will not be repeated here. The sRSS is however a new signal that needs to be implemented in SEAMCAT.

3 Algorithm

3.1 Basic principle

Assuming ideal case, the basic proposal of a CR is as follows:

- if $sRSS > \text{Detection threshold}$ -> WSD_{OFF} = no transmission = no interference
- if $sRSS < \text{Detection threshold}$ -> WSD_{ON} = interference calculation is possible

3.2 Overall Algorithm

STEP 1: Identification of the frequencies to be tested.

It is assumed that the frequency of the interfering WSD is dependent on the frequency range defined for the victim. This means that when the CR module will be activated, the interfering frequency function dialog box will be deactivated.

M is the number of possible channels that the WSD will operate in.

One can consider following possible ways to define operating frequency for the victim device:

Victim frequency = constant

- interferer frequency = Victim frequency
- $M = 1$

victim frequencies are discrete

- the possible WSD frequencies are those defined by the user
- M equals the number of discrete inputs

victim frequencies are distributed between f_{\min} and f_{\max}

- The possible WSD frequencies are $f_{\min} + (M-1) \cdot \text{victim bandwidth}$ where $(f_{\min} + (M-1) \cdot \text{victim bandwidth}) \leq f_{\max}$ (i.e. assuming that f is the center frequency)
- Extract M WSD channels

STEP 2: Assigned the WSD with a frequency

for each events {

Note: the victim operates at a single frequency f_v . Several interferers may be operating in various frequencies

if (dRSS > sensitivity) {

for each WSDs {

for channel $m = 1$ to $M+1$ (i.e. over all the WSD channels) {

STEP 2.1: Calculate the sRSS

- Calculate the sRSS (considering the unwanted mask of the DTT) at the channel m
$$sRSS(f_m) = P_{W_t}(f_m) + G_{W_t \rightarrow I_t} + G_{I_t \rightarrow W_t} + L + \text{hidden_node_margin} \quad (1)$$
where :

- P_{W_t} : is the transmit power in dBm from the W_t . The bandwidth of the sensing device (I_t) should be considered in the calculation. Note: The emission bandwidth of the W_t may be different from the I_t receiving bandwidth, therefore when the sRSS is to be calculated, a bandwidth correction factor is needed. P_{W_t} is subject to power control (p.162 of SEAMCAT Handbook). The emission spectrum mask is needed to get P_{W_t} at frequency f_m .
- f_m : is the frequency of the WSD.
- $G_{W_t \rightarrow I_t}$: is the antenna gain in dBi of the W_t , in the W_t to I_t direction
- $G_{I_t \rightarrow W_t}$: is the antenna gain in dBi of the I_t in the I_t to W_t direction
- L : is the path loss in dB between the I_t and the W_t .
- *Hidden_node_margin*: is expressed in dB (see section 3.4 for further details)

(i.e. WSD at f_m and victim at f_v) (see eq. 1)

STEP 2.2: Identification of “available” channels

- Detect if a WSD is allowed to transmit (i.e. compare to threshold) (**Sect. 3.1**)
- Store the channels that are accessible as *available_channel*
- Store the channels that are not accessible as *non_available_channel*

}

STEP 2.4: Probability of Failure (if activated)

- Determine among the channels which are blocked those which are not blocked due to the failure (if probability of failure is active)
- Update the vectors *available_channel* and *non_available_channel*

STEP 2.5: Select an available channel / determination of the WSD channel

if (*non_available_channel* < 1) (i.e. all are available){

- No frequency is blocked, the max EIRP of the WSD is considered (i.e. EIRP deduced from the Tx and antenna gain of the WSD which are inputs to SEAMCAT.) (eq.4)
- The WSD is placed randomly among the *available_channel*

}

else (i.e. one or more channels are blocked (i.e. non-available)){

if (all channels are blocked){

try another WSD → **back to STEP 2.1** and store the number of inactive WSD

}

else (not all the channels are blocked){

if (single frequency case) (i.e. frequency = constant){

No frequency is blocked, the max e.i.r.p of the WSD is considered (i.e. e.i.r.p deduced from the Tx and antenna gain of the WSD which are inputs to SEAMCAT.) (eq.4)

}

else {

Step 2.5:1: Apply the Table of Constraints

For each of the *non_available_channel*, read the associated predefined table (see Table 1) for which the “co-channel” row is synchronised to the non-available channel. Create a new e.i.r.p Table with the dimension (rows: number of *non_available_channel*, columns: number of *available_channel*)

for each of the *available_channel*{

- Extract the smallest e.i.r.p from the table. This gives the vector (available channel, e.i.r.p).

Step 2.5:2: Determination of the WSD channel /e.i.r.p

- From this vector extract the couple (fi, “max e.i.r.p”)the vector (available channel, e.i.r.p)
- if several channels are associated with the same “max e.i.r.p” , the WSD is placed randomly among the channels.

}

}

}

}

} (end of the WSD loop)

Note: Now the active WSDs are assigned a frequency and a EIRP_{max}.

Cumulate the frequency/ e.i.r.p of all the active WSDs for each event into a single vector.

Note: The below calculation is as normal to SEAMCAT
for each active WSDs {

Extract the $Tx\ power = e.i.r.p_{max} - G_{maxIt \rightarrow Vr}$

Calculate $iRSS_{unwanted}$ (i.e. victim at f_v) (see eq. 5) (**Sect. 4**)

Calculate $iRSS_{blocking}$ (i.e. victim at f_v) (see eq. 6) (**Sect. 4**)

Calculate $iRSS_{overloading}$ from the interfering WSD to the at the DTT victim receiver.

}

Calculate the $iRSS_{comp}^{unwanted} = \sum_{i=1}^{numberOfActiveWSD} iRSS_i^{unwanted}$

Calculate the $iRSS_{comp}^{blocking} = \sum_{i=1}^{numberOfActiveWSD} iRSS_i^{blocking}$

Note: If none of the WSDs are active $iRSS_{comp} = -1000$ dB (by default) to allow the interference calculation.

```

}
else{
    Skip this event
}
}

```

STEP 3: Calculate the Interference

3.3 Probability of failure

This feature is input selectable (by default, it is de-activated). The probability of failure may account for the failure in selecting wrongly a *non_available* channel for one event.

This means that when a failure appears, a channel which was initially selected as occupied by a victim DTT becomes “wrongly” available for the WSD to transmit. This result in a “conflict” situation.

For instance with a defined $p_{failure}$, that means that for x total *non_available* channels, $x * p_{failure}$ channels will become available. $p_{failure}$ is an input parameter.

This feature is for further development.

3.4 Hidden Node problem

Spectrum sensing as a cognitive technique needs to account for so called hidden node problem. This arises because the receiver of a licensed user is better able to receive the licensed transmissions than the cognitive device can (due to their different spatial locations). Figure 4 illustrates an example where the DTT considered as a victim and the WSD is the interferer.

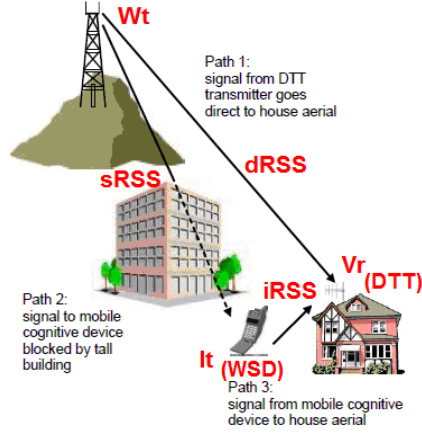


Figure 4: Illustration of the hidden node problem and its relationship with SEAMCAT terminology.

A house receives a DTT signal using a rooftop directional antenna mounted clear of surrounding buildings (path 1 - dRSS). Nearby is a mobile cognitive device attempting to detect the same signal at street level, but it is blocked by surrounding buildings (path 2 - sRSS) and therefore much reduced in strength. The cognitive device might erroneously conclude that there are no transmissions and hence no active nearby receivers, transmit and cause harmful interference to the rooftop antenna (path 3 - iRSS).

In order to take into account hidden node margin then calculating sRSS following equation can be used:

$$sRSS \text{ (dBm)} = P_{Wt} \text{ (dBm)} + G_{Wt} \text{ (dBi)} + G_{it} \text{ (dBi)} + L \text{ (dB)} + \text{hidden_node_margin (dB)} \quad (2)$$

Note: In the equation above hidden-node margins will be different depending on the different licensed services in the considered frequency band.

3.5 sRSS calculation

If there is a need to have a sRSS vector output, it is proposed that an average over the number of interferer be made. It is not recommended to have a matrix due to the memory limitation on the SEAMCAT calculator (i.e. having 100 WSD for 20000 snapshot would result in a 100x20000 point matrix).

$$sRSS_{average} = \frac{1}{N_{WSD}} \sum_{i=1}^{numberofWSD} sRSS_i \quad (3)$$

where N_{WSD} is the number of WSD.

4 Adjacent channel scenario

In the case where the WSDs are not allowed to transmit in the same operating frequency as for the victim DTT device, the WSDs can decide to transmit in the adjacent bands or channels. This scenario is illustrated in Figure 5 In this example the WSDs have sensed that in the channel 6 there is a victim system (here a DTT), therefore the WSDs will choose other channels to transmit.

The maximum permitted in-block and out-of-block EIRP of autonomous CRs would be specified as a function of the guard band with respect to DTT channels used in the local proximity of the CR. The available guard band would be identified by comparison of the detected DTT signal powers against a fixed detection threshold. [SE43(10)19]

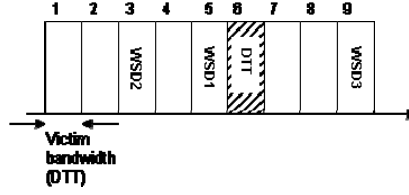


Figure 5: Illustration of WSD1 detecting a victim device in channel 6 and as a consequence decides to operate in channel 3 which is available.

The purpose of the SEAMCAT simulation is to investigate the level of interference created by WSDs to the DTT victim device. Therefore the $iRSS_{unwanted}$ and $iRSS_{blocking}$ for a WSD will be computed.

As a reminder, the EIRP (Equivalent isotropically radiated power) is defined as:

$$EIRP_{max} = P_{It} - L_c + G_{maxIt \rightarrow Vr} \quad (4)$$

where L_c is the cable loss in dB. We will neglect L_c .

Extract the $Tx\ power = EIRP_{max} - G_{maxIt \rightarrow Vr}$ from **Step 2.5** of the algorithm in section 3.2.

Calculate the $iRSS_{unwanted}$ from the WSD to the victim DTT device such that:

$$iRSS_{unwanted} = Tx\ power + Emissions\ mask / (unwanted_emission_floor) + G_{It \rightarrow Vr} + G_{Vr \rightarrow It} + L_{Vr \rightarrow It} \quad (5)$$

Calculate the $iRSS_{blocking}$ from the WSD to the victim DTT device such that:

$$iRSS_{blocking} = Tx\ power + G_{It \rightarrow Vr} + G_{Vr \rightarrow It} + L_{Vr \rightarrow It} \quad (6)$$

Note: Eq.5 and 6 are unchanged from the “normal” SEAMCAT calculation.

As a result, the interference calculation can be performed on the summation of the $iRSS_{unwanted}$ per channel and $iRSS_{blocking}$ per channel in the case where there are multiple active WSDs per channel.

The In-block input values (dBm), as defined in table 1, will require a new interface.

DTT in use at	In-block CR EIRP _{max} limit (dBm)
co-channel	$-\infty$
$n \pm 1$	-12.8
$n \pm 2$	3.2
$n \pm 3$	11.2
$n \pm 4$	16.2
$n \pm 5$	20.2
$n - 6$	16.2
$n + 6$	21.2
$n \pm 7$	22.2
$n \pm 8$	23.2
$n - 9$	4.2
$n + 9$	23.2
$n \pm 10$	24.2
$> n \pm 11$	25.2

Table 1: Example of In-block CR emission limits as a function of guard band with respect to serviced DTT channels as discussed in SE43 (source SE43(10)18).

5 User input/output

5.1 Input

- Detection threshold (in dBm) (new)
- Device is CR (selectable entry) (new) (see Figure 6)
- Propagation model for the $W_t \rightarrow I_t$ (reuse existing propagation models)
- Probability of spectrum sensing failure (in %) (new)
- Hidden node margin (dB) (new)
- Define the bandwidth of the sensing device (i.e. I_t) (in kHz) (new)
- Emission mask of the W_t (see Figure 8) (new)
- Unwanted emission floor of the W_t (see Figure 8) (new) – due to PC at the W_t .
- EIRP *in-block* mask (new)
- EIRP *out-of-block* mask (re-use of the I_t unwanted emission floor).

This requires a new tab as shown in Figure 6 with the proposed content in Figure 7 and 8.

5.2 Output

- Average sRSS ($sRSS_{average}$) vector (dBm) (new) (see Figure 9)
- dRSS vector (interface already existing)
- iRSS_{comp} (unwanted/blocking) vector (interface already existing)
- Probability of interference for WSD (no change in the display to be expected)
- Average value of active CR interferer (N_{CR_active}) (new)

6 GUI Interface

6.1 Interfering link/General

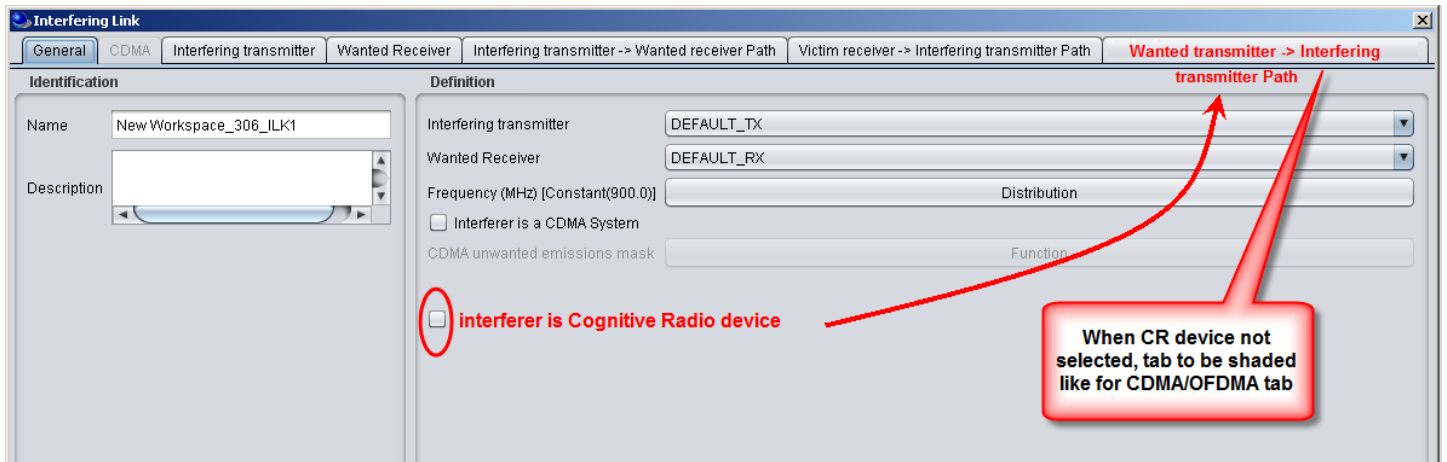


Figure 6: Illustration of a proposed new tab.

6.2 Interfering link/wanted transmitter → interfering transmitter Path (new tab)

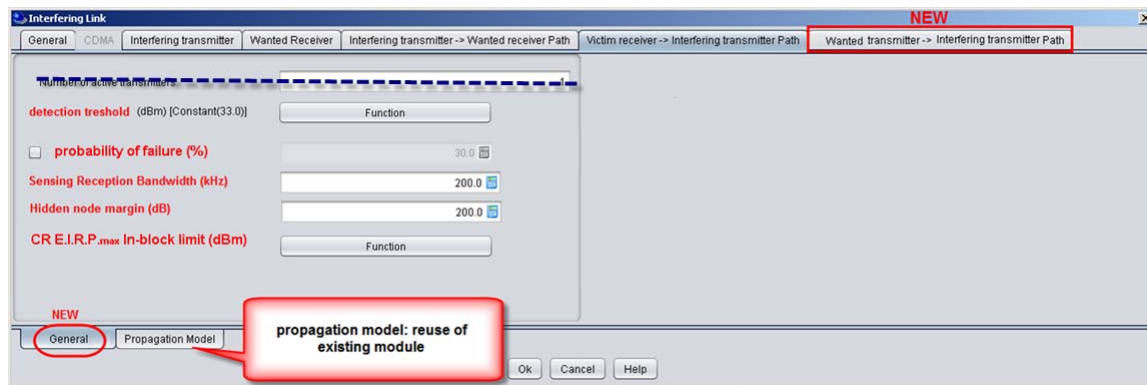


Figure 7: Illustration of a proposed content for the new tab.

6.3 Emission mask of the Wt (new Input parameter)

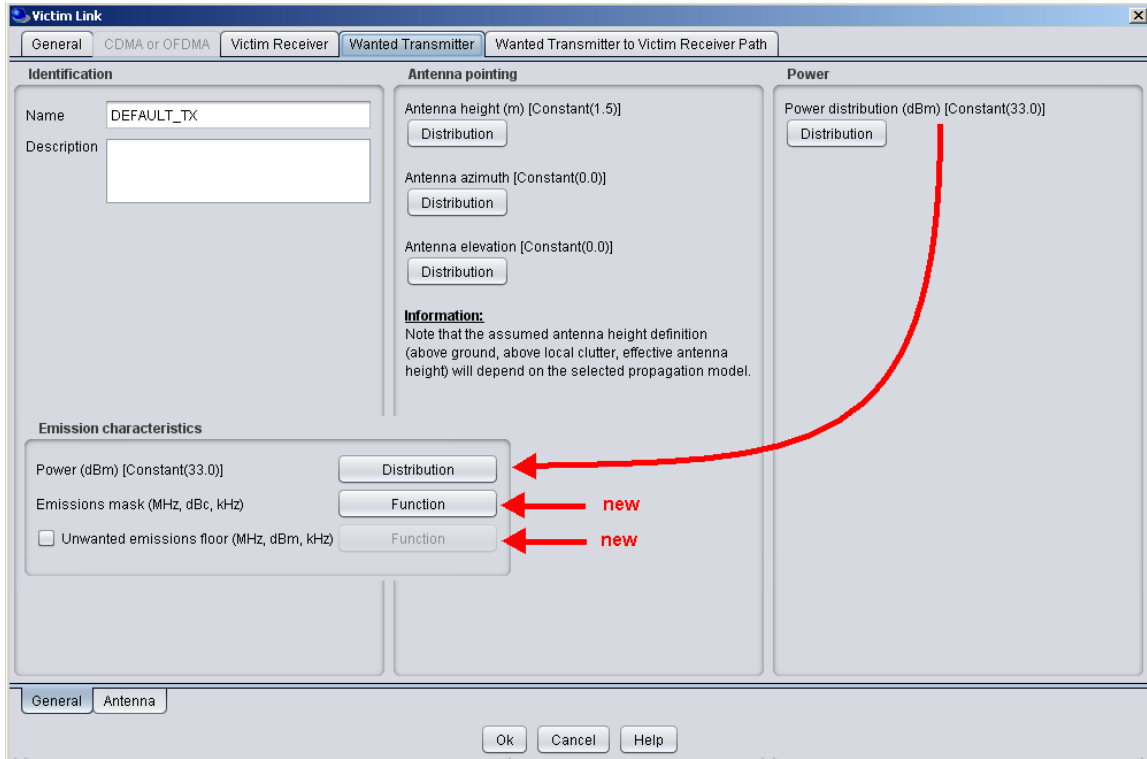


Figure 8: Illustration of how proposed Emission mask of the Wt can be implemented

6.4 New vector interface is required for sRSS

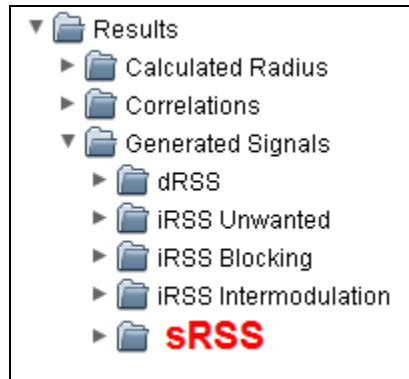


Figure 9: Illustration of a proposed new output vector.