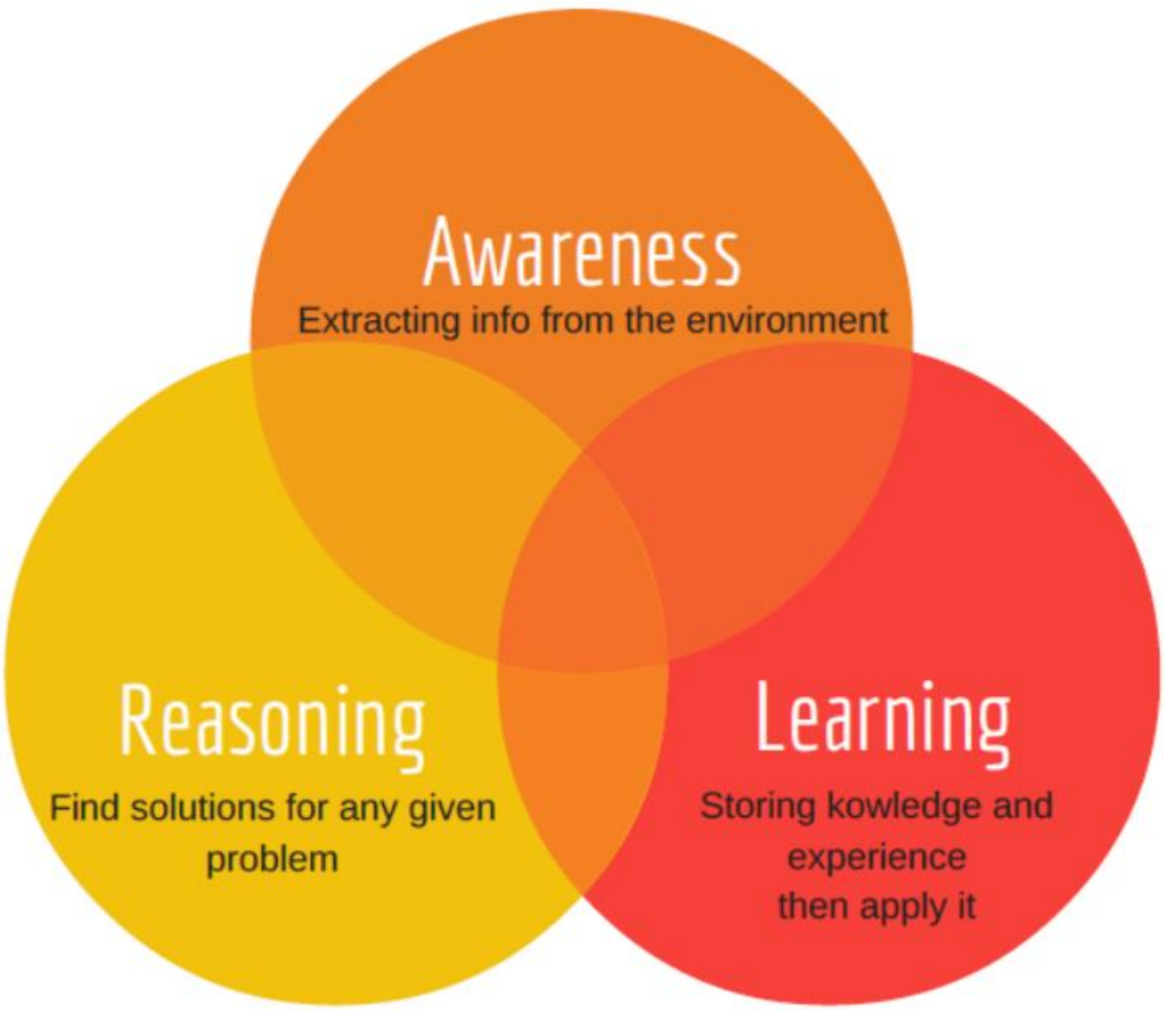
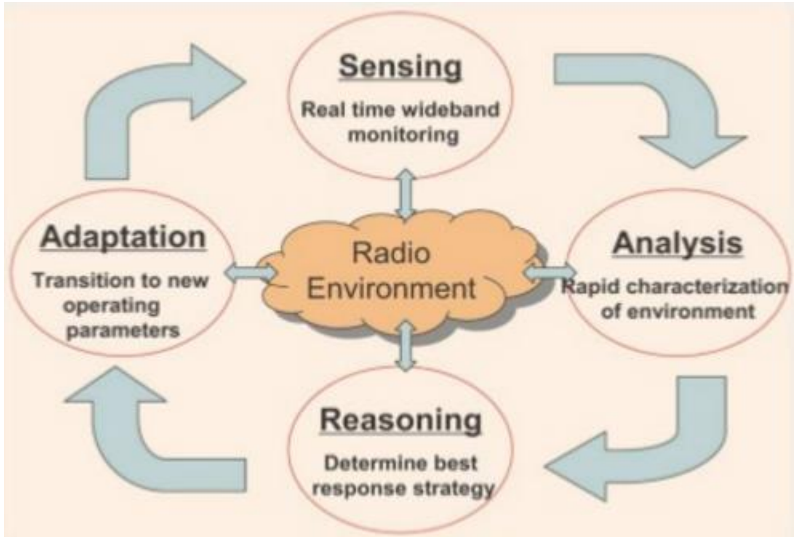
CR

COGNITIVE RADIO

OBSERVING THE OUTSIDE WORLD | COGNITIVE CYCLE





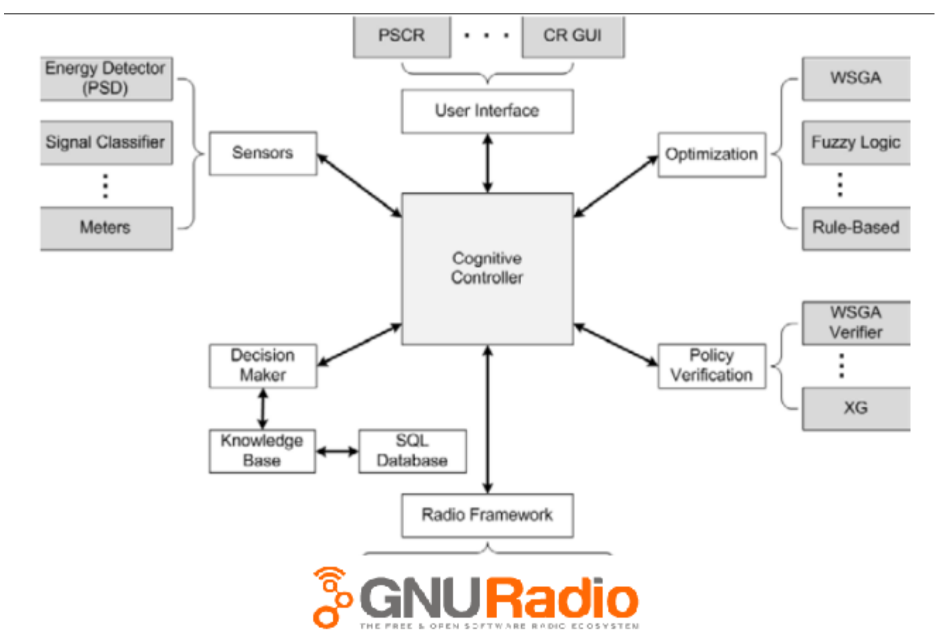
In Order to observe the outside world, we need sensors to sense the external environment. Then those sensors communicate directly to the controller who acts and decides.

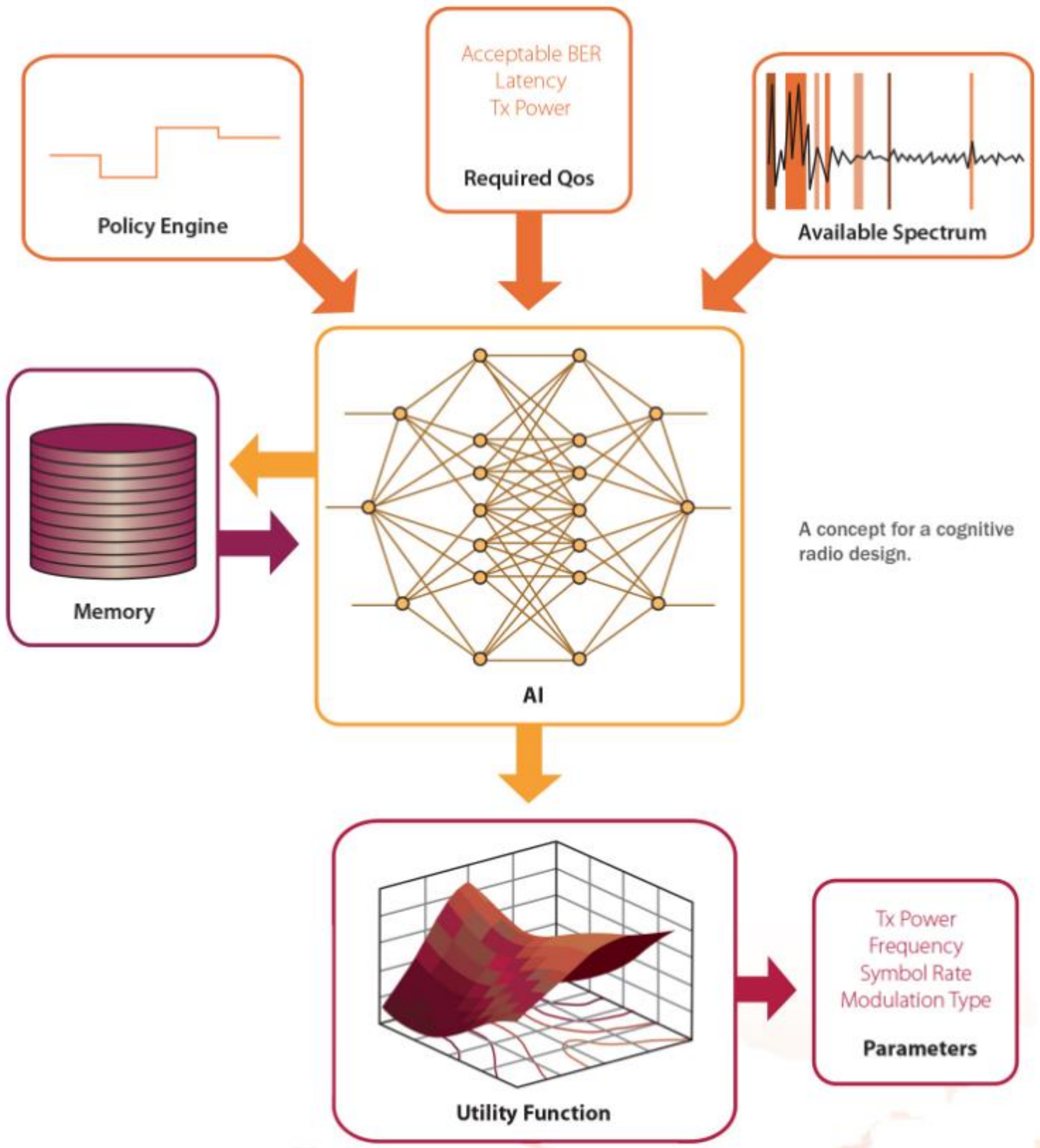
The sensors are represented as the RF front Ends which have the capabilities to sense a wide or a narrow of a certain frequency band. The Signals/Data then shall be acquired (Amplified and Digitized) so mainly Data shall be received via the RF front end and then interface it to the Digital Back end for processing.

Here are the sensing peripherals key roles are done.

The Data are then passed to some kind of Artificial Engine Which is mainly handle the data to Learn, Adapt and Making the proper decision. This branch of AI is called Machine Learning

Machine Learning: "Computational Learning using some kind of enhanced algorithm to learn and make predictions on data"

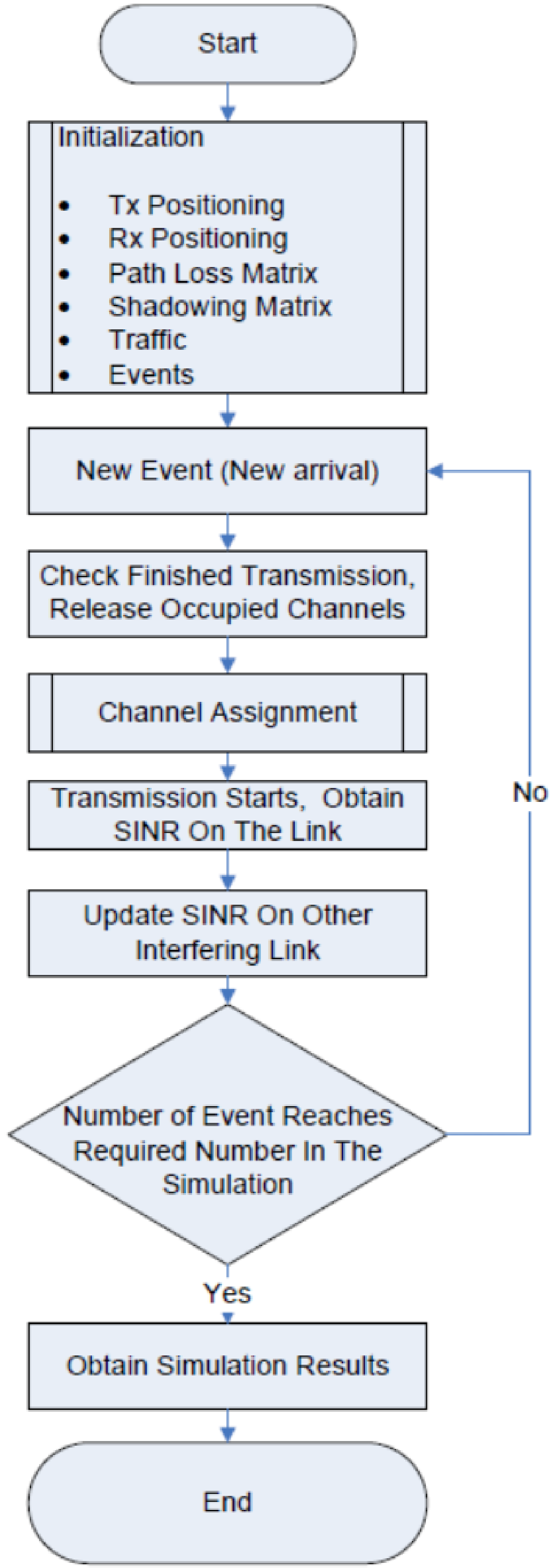




A concept for a cognitive radio design.

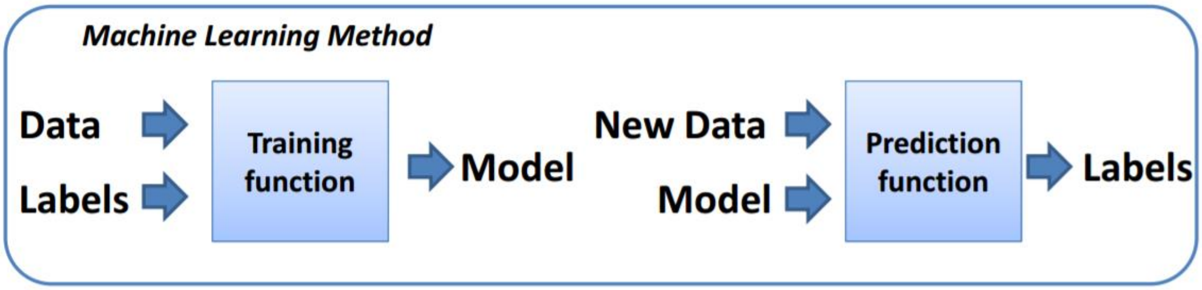
Technical Approach:

Cognitive radios are aware of their environment and intelligently adapt their performance to the user's needs. A CR is a software defined radio with a "cognitive engine" brain. Conceptually, the cognitive engine responds to the operator's commands by configuring the radio for whatever combinations of waveform, protocol, operating frequency, and networking are required. It monitors its own performance continuously, reading the radio's outputs to determine the RF environment, channel conditions, link performance, etc., and adjusting the radio's settings to deliver the needed quality of service subject to an appropriate combination of user requirements, operational limitations, and regulatory constraints. We call these processes "reading the radio's meters" and "turning the radio's knobs" for short.


Start
Initialization
• Tx Positioning
• Rx Positioning
• Path Loss Matrix
• Shadowing Matrix
• Traffic
• Events
New Event (New arrival)
Check Finished Transmission, Release Occupied Channels
Channel Assignment
Transmission Starts, Obtain SINR On The Link
Update SINR On Other Interfering Link
Number of Event Reaches Required Number In The Simulation
No
Yes
Obtain Simulation Results
End

A closer Look To the AI

Machine Learning: “Computational Learning using some kind of enhanced algorithm to learn and make predictions on data”

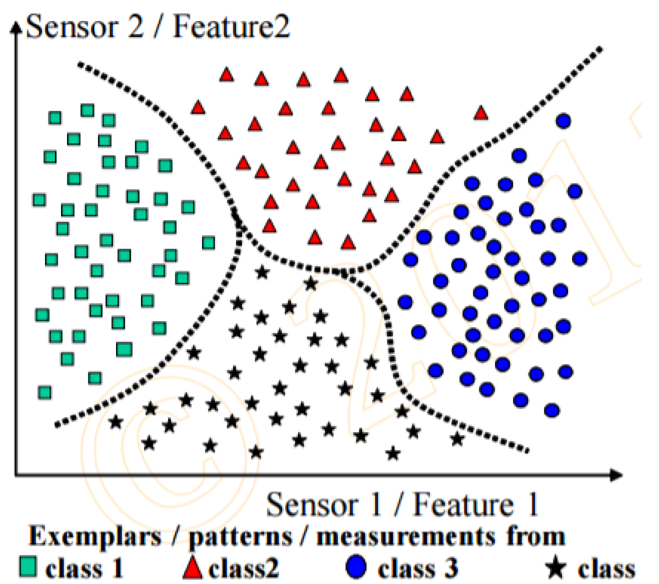


Feature Extraction: Determining those components of the signal that are deemed most relevant to the application at hand including time domain analysis to extract features like the mean and variance and Frequency domain analysis to filter and reshaping the Data according to the application, determine the modulation scheme and estimate the frequency channel.
A Feature is a variable (predictor) believed to carry discriminating and characterizing information about the objects under consideration. We put those features into a vector where a Feature vector is A collection of d features, ordered in some meaningful way into a d-dimensional column vector, that represents the signature of the object to be identified.
After Extracting the Features, we then shall classify them.

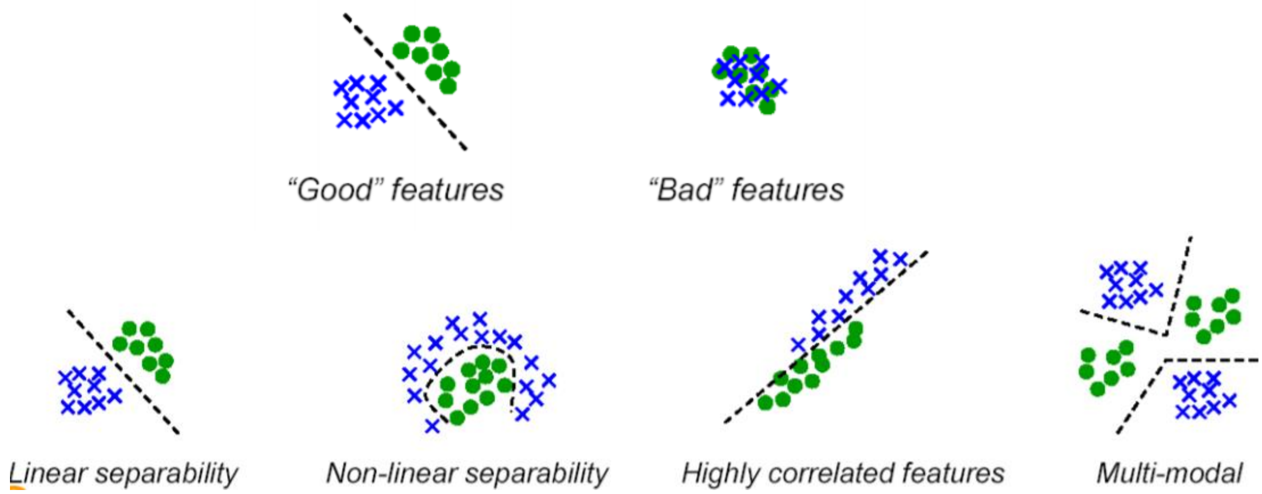
Classification: Automated analysis of the features to determine what specific action should be taken based on the current values of the features, so it mainly assigns a class which is based on some patterns according to the extracted features.

Feedback / Retraining: Taking advantage of the cognitive plasticity of the algorithm to adjust to the new environment.

$$\mathbf{x} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_d \end{bmatrix} \begin{array}{l} \textit{feature 1} \\ \textit{feature 2} \\ \\ \textit{feature d} \end{array}$$



Training Data: Data used during training of a classifier for which the correct labels are a priori known

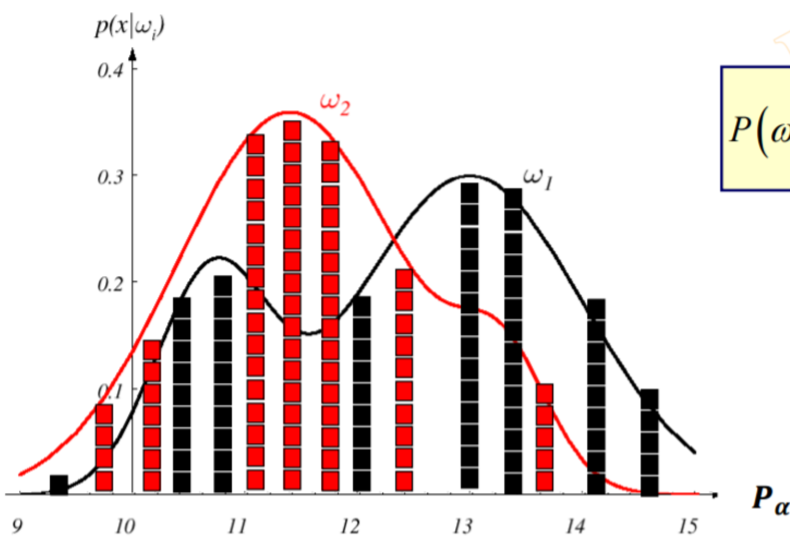


Classification Illustation

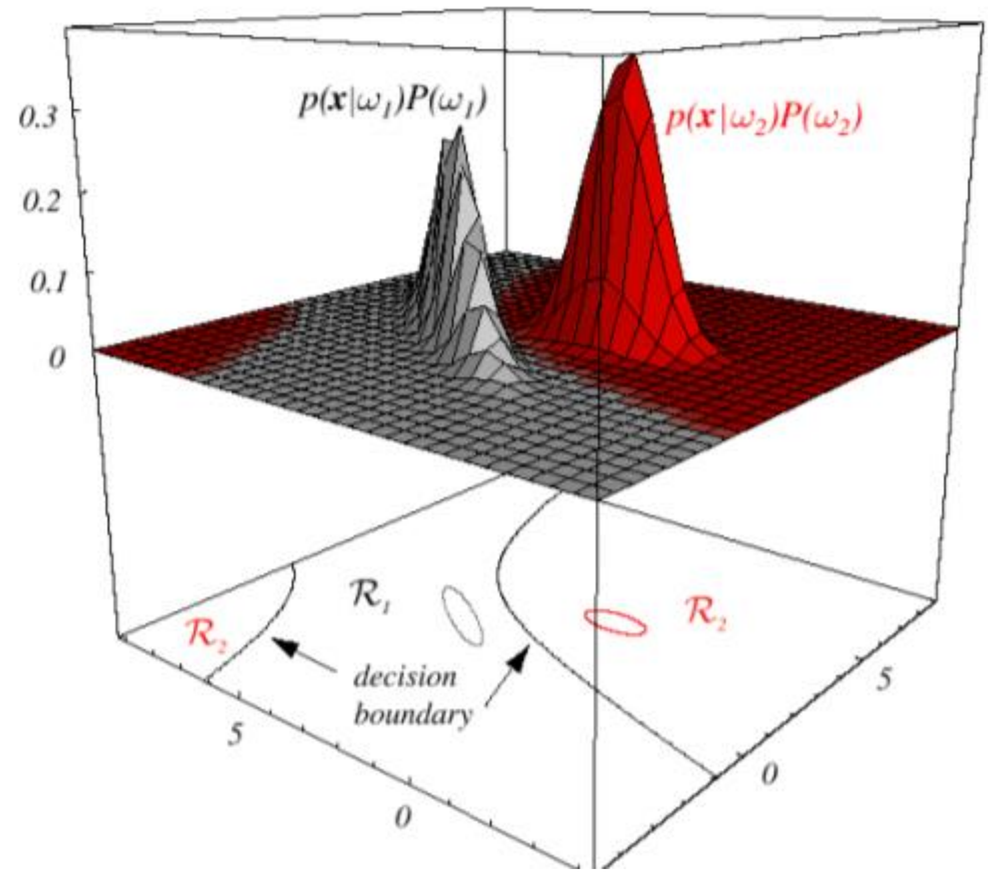
ω_1: Left → $P(x \mid \omega_1)$: Class conditional probability for LEFT

ω_2: Right → $P(x \mid \omega_2)$: Class conditional probability for RIGHT

Likelihood: For example, given that RIGHT (ω_2) has been observed, what is the probability of P_α being between 11 and 12? Or simply, what is the probability that th α band power for a RIGHT indication between 11 and 12



$$P\left(\omega_j \mid x\right) = \frac{p\left(x \mid \omega_j\right) \cdot P\left(\omega_j\right)}{p\left(x\right)}$$



0.3
0.2
0.1
0
$p(\mathbf{x}|\omega_1)P(\omega_1)$
$p(\mathbf{x}|\omega_2)P(\omega_2)$
$\mathcal{R}_1$
$\mathcal{R}_2$
$\mathcal{R}_2$
decision boundary
5
0
5
0

The Cognitive Radio Networks needs an understanding of the environment in which it operates, an understanding of the communication requirements of the user(s), an understanding of the regulatory policies which apply to it and an understanding of its own capabilities.' Getting these four inputs is what we mean by the phrase 'observing the outside world'.

Taking Actions (Making a Decision)

To take action from a frequency perspective
the cognitive radio must observe which signals are currently being transmitted, which channels are free, the bandwidth of those channels and perhaps whether the available channels are likely to be short lived or more durable (spread spectrum).

To take action from a spatial perspective,
the cognitive radio needs to make observations about the spatial distribution of systems that must be avoided, or the spatial distribution of interferers and of the target radios. The cognitive radio needs to be able to monitor its power output and the power output of other systems.

To take action to make a signal more robust or to maximize the throughput of the transmitted signal,
the cognitive radio needs to make observations about the signal-to-noise ratio (SNR) at the target receivers, about the bit error rates and about the propagation conditions experienced by the transmitted signal (e.g. delay spread, Doppler spread/Shift).

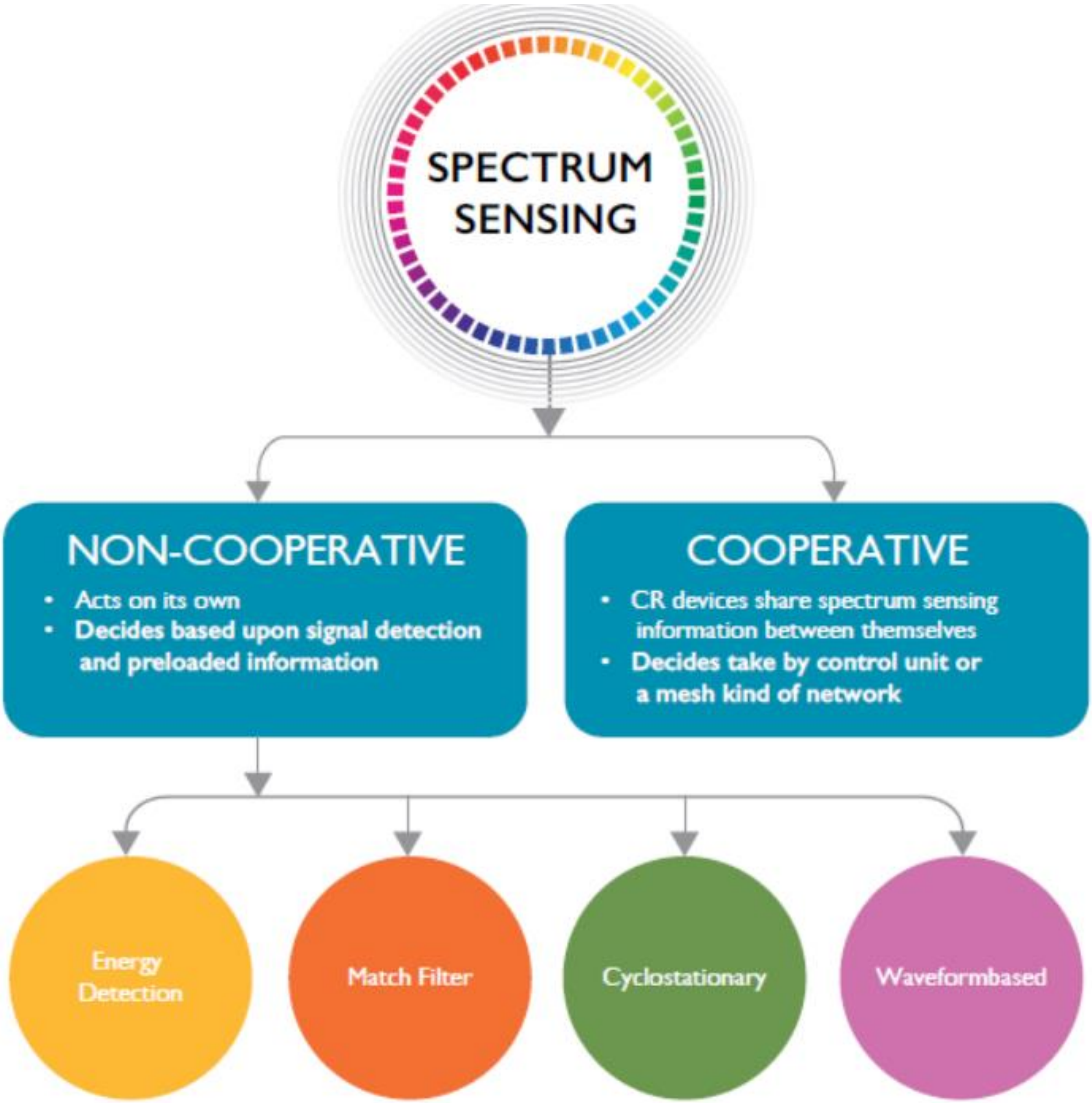
To take actions that focus on maximizing the capacity of a channel
the cognitive radio needs to make observations about the channel. Observations about the cognitive radio's location, the date and day.

1. Firstly the cognitive radio can get observational data as a natural byproduct of its normal mode of operation. This is the simplest scenario. So, for example, time and date are typically available in many operating systems. The transmit power setting may be readily observable. As a more complicated example a node in a network may know how many neighbours it has as a consequence of some aspect of its routing protocol and hence node degree is readily available. In other words the observations in this category are simply available as part of the normal operating process of the radio and no elaborate processing is needed to access the observations.[1]

2. Secondly a cognitive radio can make observations via dedicated extra hardware such as a GPS, simple sensors (temperature, pressure, acceleration) or battery meters. A GPS, for example, is capable of determining location (to a certain degree of accuracy) which in turn can be used to determine velocity over time. A temperature sensor could provide information on operating conditions and, together with the output from a battery meter, indicating remaining operating lifetime, could for example be used to manage radio resources. There is no assumption that all cognitive radios will have such extra equipment, but it is certainly a possibility that some will.

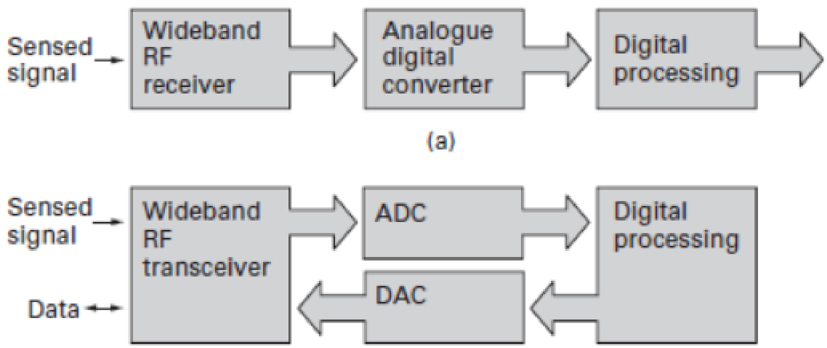
3. Thirdly a cognitive radio can use specialised signal analysis techniques for extracting relevant observations from signals that the cognitive radio captures, either through the radio with which it normally communicates or through additional radio sensing equipment. The analysis techniques could be used to determine the presence or absence of signals, to discover details of the features of the signals which are present, to determine interference levels, or to evaluate signal-to-noise ratios, etc. In other words, the analysis would generate a set of observations that all tend to be connected with understanding the RF environment

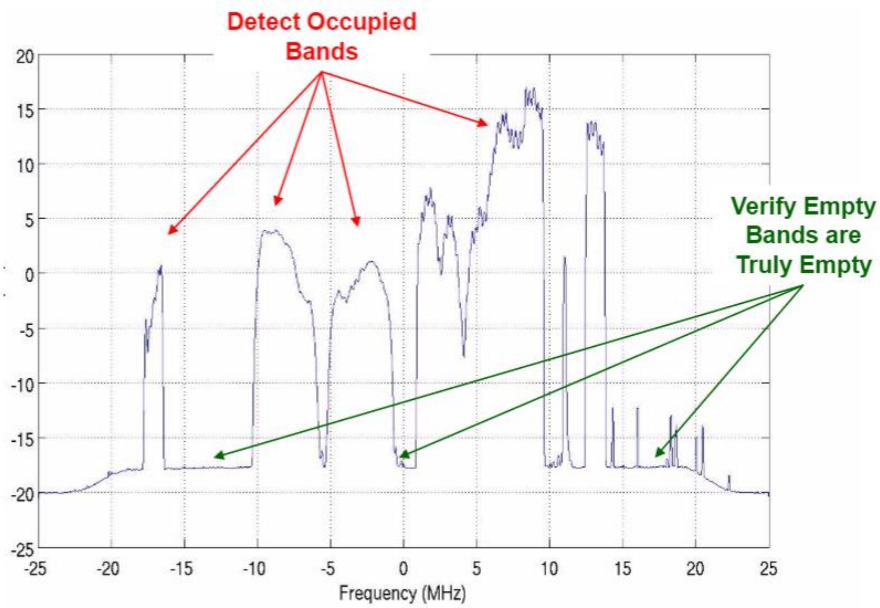
4. Fourthly a cognitive radio can learn from experience about the world in which it is operating. It can learn where network coverage is poor. It can learn the preferences of the user of the system. It can learn the behavioural pattern of primary users.


SPECTRUM
SENSING
NON-COOPERATIVE
• Acts on its own
• Decides based upon signal detection and preloaded information
COOPERATIVE
• CR devices share spectrum sensing information between themselves
• Decides take by control unit or a mesh kind of network
Energy Detection
Match Filter
Cyclostationary
Waveformbased

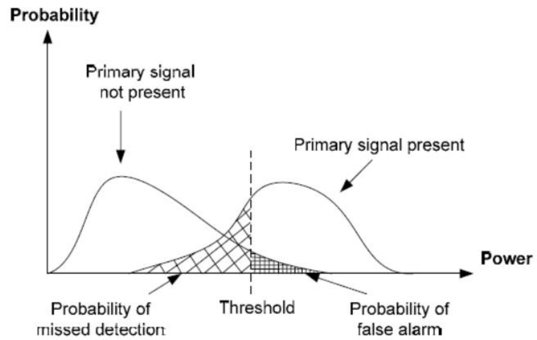
The system consists of a wideband RF receiver that captures the incoming signal. The receiver must be capable of capturing the entire range of frequencies in which the secondary user plans to operate (needs appropriate RF components and a suitable wideband antenna). The captured signal is then converted from analogue to digital and then processed in the digital domain

A variety signal processing techniques can be used to examine the content of the signal and determine the presence of spectrum users. Once white space has been identified the cognitive radio can transmit in that white space. The cognitive radio can contain dedicated sensing circuitry, in which case a sensing system such as that shown would be a separate entity from the main radio that is used for communication purposes. The other option is for there to be a single radio only. In this case the radio must divide its time between the sensing and communications functions.





Energy Detection



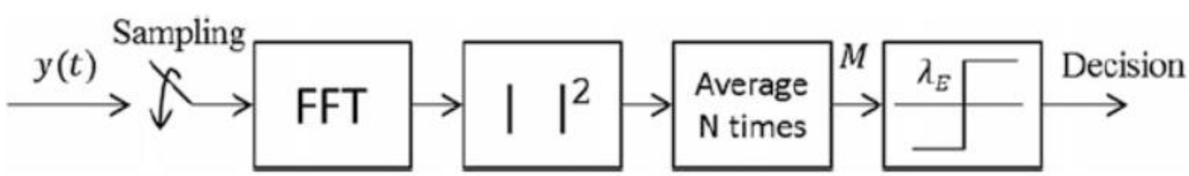


Fig. 1 Schematic representation of energy detection spectrum sensing

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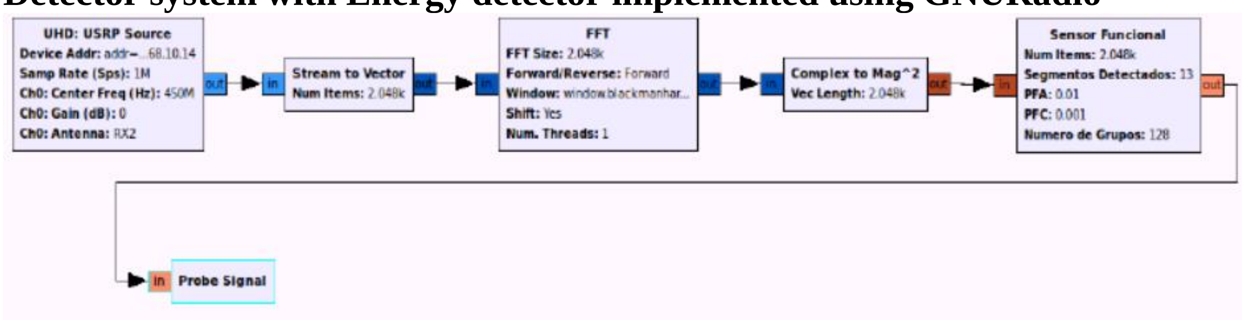
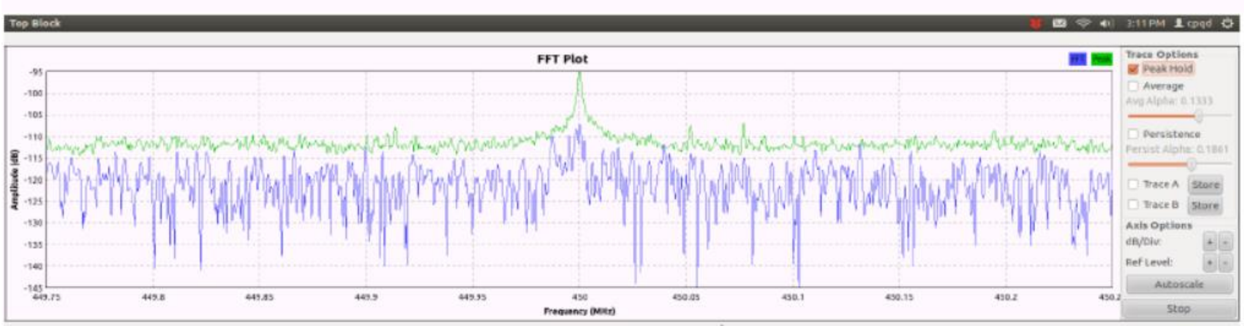
Detector system with Energy detector implemented using GNURadio





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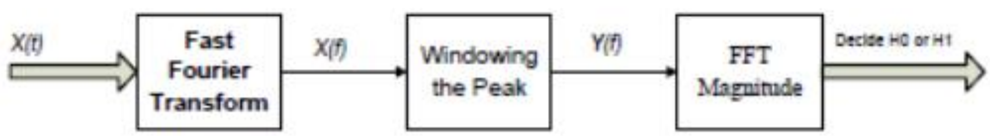
Energy Detection

In energy detection method we measure the energy of available radio resource and compare it against a predefined threshold level. If the measured energy falls below the defined threshold level spectrum is marked as available. When the measure energy level is above the defined threshold, it's considered as occupied. Energy detection method does not require any prior information of the signal. In simple words it does not care about the type of modulation used for transmission of signal, phase or any other parameter of signal. It simply tells if the radio resource is available at any given time instant or not without considering the PU and SU [10]. Hypothetically, energy detection can be considered as a method based on binary decision, which can be written as follows:

$$\boldsymbol{x(t) = n(t)} \qquad \boldsymbol{H0} \tag{1}$$

$$\boldsymbol{x(t) = s(t) + n(t)} \quad \boldsymbol{H1} \tag{2}$$

Where s(t) is the received signal and n(t) is the Additive White Gaussian Noise (AWGN) i.e. equally distributed all over the signal. H0 and H1 represent the two outcomes of the energy detection method [4]. The energy detection method's working principal can be explained with the Figure 2.3



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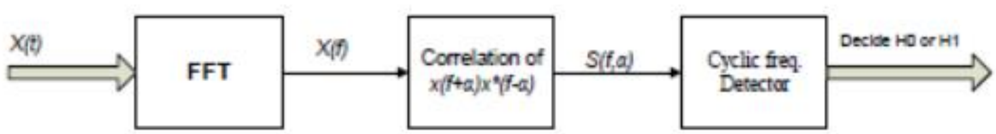
Cyclostationary Method

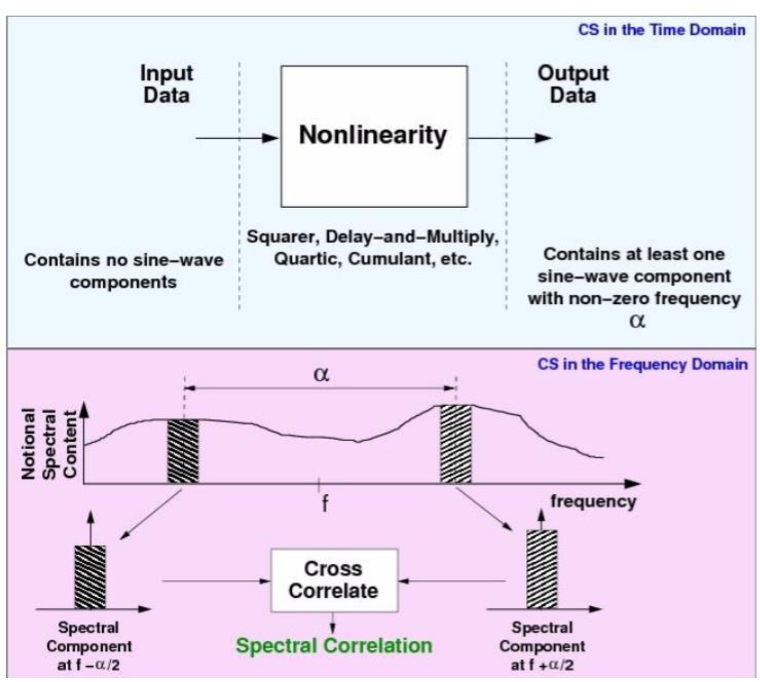
A Cyclostationary process is defined as the statistical process which repeats itself cyclically or periodically [6]. Communication signals are Cyclostationary with multiple periodicities. Mathematically Cyclostationary detection can be performed as given in equation (3):

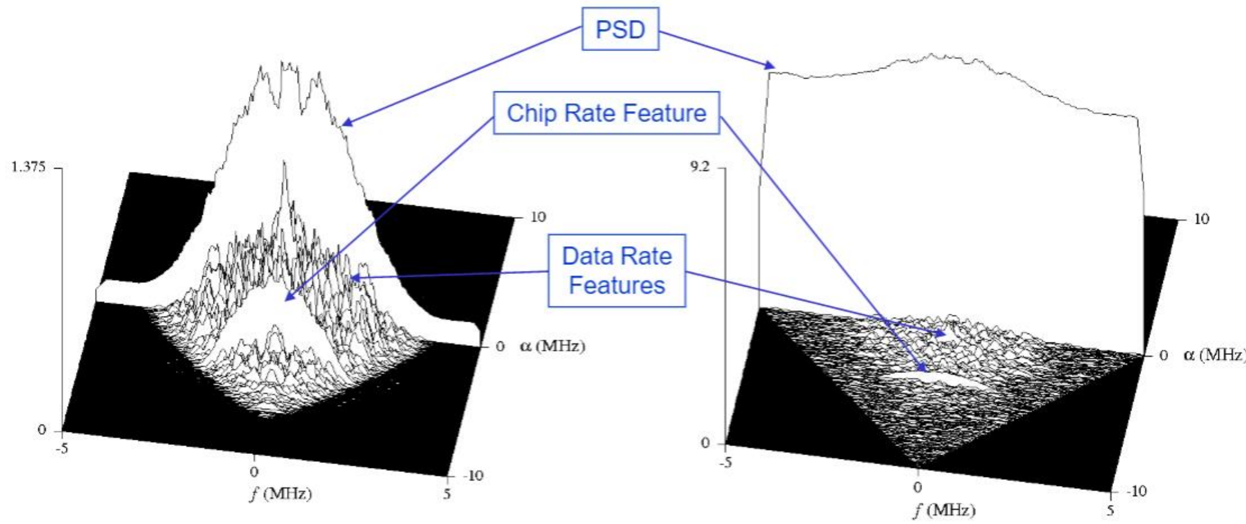
$$Rx(T) = E\left[x(t+T)x^{*}(t-T)e^{-j2\alpha\pi t}\right] \quad (3)$$

The equation shows the autocorrelation of the observed signal x(t) with periodicity T, E represents the expectation of the outcome and α represents the cyclic frequency [6]. After autocorrelation Discrete Fourier Transform over resulting correlation is performed to get the desired result in terms of frequency components. The peaks in the acquired data give us the information about the spectrum occupancy. The Cyclostationary detection method requires prior

knowledge of periodicity of signal and it can only be used with the signal possessing Cyclostationary properties. The implementation of Cyclostationary method is shown in Figure 2.4.



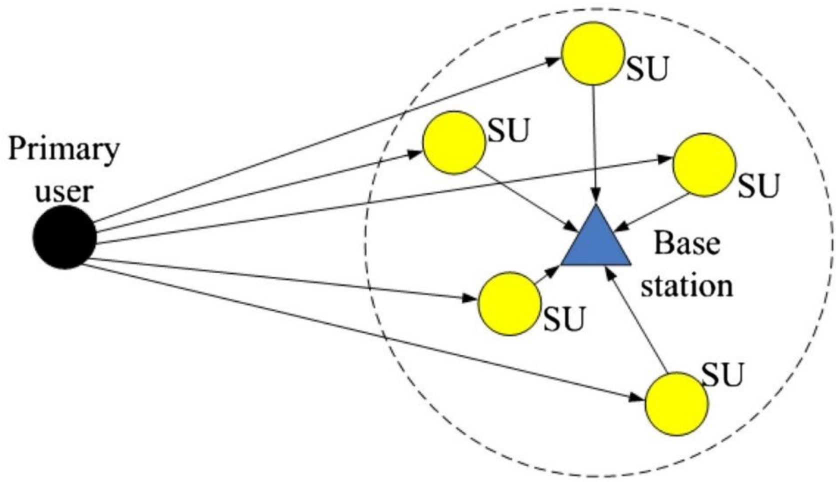




The Power of CSP: Noise Tolerance

CSS-COOPERATIVE SPECTRUM SENSING

We consider a CR network composed of K SUs and a base station (fusion center), as shown in Figure 1. We assume that each SU performs energy detection independently and then sends the local decision to the base station, which will fuse all available local decision information to infer the absence or presence of the PU.



In the conventional hard combination CSS scheme, each cooperative partner *i* makes a binary decision based on its local observation and then forwards its one-bit decision D_i ($D_i = 1$ stands for the presence of the PU, and $D_i = 0$ stands for the absence of the PU) to the base station. At the base station, all one-bit decisions are fused together according to the logic decision fusion rule and the final decision can be obtained as

$$Y = \sum_{i=1}^{K} D_i \begin{cases} \geq k & H_1 \\ < k & H_0, \end{cases}$$

where H_0 and H_1 denote the decision made by the base station that the PU is present or absent, respectively. The threshold k is an integer, representing the "n-out-of-K" rule. It can be seen that the OR rule corresponds to the case of $k = 1$, the AND rule corresponds to the case of $k = K$, and in the VOTING rule k is equal to the minimal integer larger than $K/2$.