Chapter 3

Spectrum Sensing Method and Fading Environment

3.1 Introduction

The most crucial CR Network task is spectrum sensing. Cognitive radio is constantly set up to be open to changes in the radio environment. The capability of CR to find the spectrum holes is provided by the spectrum sensing task. Spectrum sensing aids the cognitive user in reaching this goal by efficiently and reliably locating the available spectrum. Spectrum sensing is really useful for cognitive users (CR) in detecting the presence of primary user signals for the purpose of protecting the primary user's transmitted signal. Cognitive users can quickly scan to determine whether the primary users have started using the spectrum for transmitting data, which allows for faster evacuation of the spectrum if necessary. For checking that PU's signal emissions cause no more interruption than is acceptable, this is more crucial. Cooperation mechanisms amongst these tertiary users must also be built, and the provision of additional cognitive radio is also required. Several mechanisms exist for spectrum sensing, each with its own set of potential benefits and drawbacks. Ideally, a spectrum sensing device would provide a holistic image of the environment across the whole radio frequency range. In this way, the CR network can forecast spectrum usage by analyzing independent variables such as frequency, space and time. It has traditionally been a difficult task to distinguish the channel used by licensed (PU) user transmitters from those used by cognitive users. As a result, transmitter detection algorithms have their own unique significance in the field of spectrum sensing.

3.2 Analytical Model of Spectrum Sensing

Spectrum sensing is a method that can be used to determine the existence of a signal in noisy environmental conditions. Spectrum sensing can also be broken down into its most basic form, which is that of a binary hypothesis issue, which can be stated as [11], [14], [15], [22], [23].

$$H_0 : \quad y(k) = n(k) \tag{3.1}$$

$$H_1 : \quad y(k) = x(k) + n(k) \tag{3.2}$$

In above expression $x(k)$ is the transmitted signal at instantaneous of k from primary user, $y(k)$ is the signal received by secondary user and $n(k)$ is the Additive-White-Gaussian-Noise. It may be rewritten to be more complicated and realistic by taking into account the faded and shadowed wireless environment effects that are represented by the complex random variable as (h) [14], [15], [22].

$$H_0 : \quad y(k) = n(k) \tag{3.3}$$

$$H_1 : \quad y(k) = h \bullet x(k) + n(k) \tag{3.4}$$

Below given Figure 3.1 describes the different possibilities of detection of existence for primary user [15].

a) Stating H_0 as true when H_0 is true $(H_0 \mid H_0)$: Decision is right
b) Stating H_1 as true when H_1 is true $(H_1 \mid H_1)$: Decision is right
c) Stating H_0 as true when H_1 is true $(H_0 \mid H_1)$: Decision is wrong
d) Stating H_1 as true when H_0 is true $(H_1 \mid H_0)$: Decision is wrong

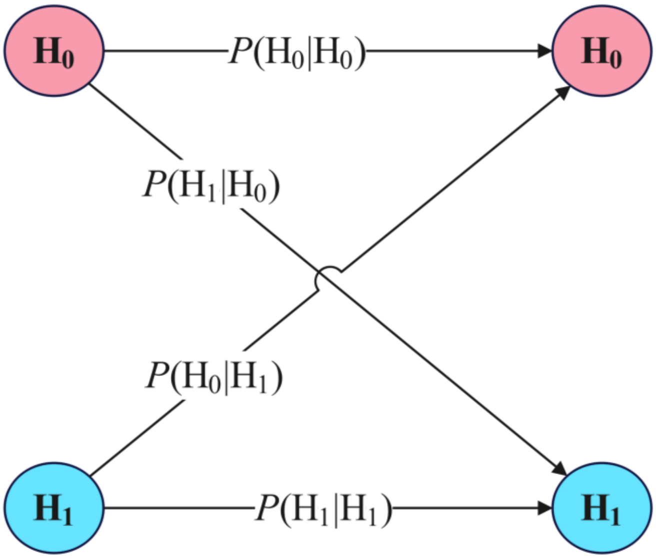

Figure 3.1: Hypotheses testing and possibilities of detection for existence of PU

Possibilities (a) and (b) are considered valid detections, whereas possibility (c) is referred to as the missed-detection. Possibility (d) is referred to as the false-alarm. Basically, a detector aims to make as much accurate detection as possible while minimizing false-alarm and missed-detection rates.

3.3 Spectrum Sensing benchmarks for Performance

The circumstances under which spectrum sensing techniques are applied may affect their effectiveness. Because of this, it is crucial to assess the circumstance and pick the most suitable course of action. Here, we will discuss the various benchmarks that can be used to judge the sensing methods performance.

- **False-Alarm-Probability**: It refers to the possibility that the detector will indicate the existence of the PU despite the fact that the PU is not actually present. When performing a test to determine whether or not a binary hypothesis is true, there are two possible kinds of Possibility: Possibility (c) and Possibility (d), respectively [15]. If H_1 is accepted when H_0 is found to be true, then a Possibility (d) has been made. It is common practice to refer to the probability of committing a Possibility (d) as the false-alarm-probability. The false-alarm-probability is an important design parameter since it leads to missed spectrum opportunities. As a result, effective management of the probability of false-alarms is essential for effective spectrum use [15], [22], [23].

- **Missed-Detection-Probability:** It is the likelihood that the detector will report that PU is not present, despite the fact that PU is actually present in the environment. If H_0 is acknowledged while H_1 is correct, then a Possibility (c) has been made. Missed detection probability, also known as Possibility (c) is the result of the probability of missed detection and can lead to collisions with the PU transmission and, as a result, a reduced rate for both the PU and the SU, respectively [22]. Missed detection probability comes about as a result of probability of missed detection and is also referred to as probability of missed detection. The regulation of the probability of missed detection and false alarm can be assisted by the establishment of distributions of decision statistics [22], [23].

These indices can be referred to as the following in terms of probability:

$$Detection\ probabilty\ (P_d) = \quad prob(H_1 \mid H_1) \tag{3.5}$$

$$False - alarm - probability(P_{fa}) = \quad prob(H_1 \mid H_0) \tag{3.6}$$

$$Missed - detection - probability(P_{md}) = \quad prob(H_0 \mid H_1) \tag{3.7}$$

3.4 Spectrum Sensing Methods

The evolution of wireless technologies in the past few years has been nothing short of astonishing. The ever-increasing population of customers results in an ever-increasing level of demand for wireless networks to suit their requirements. There has been an increase in the demand for additional radio spectrum to accommodate cellular technology. This is due to the fact that services providing high internet speeds require a significant amount of bandwidth. The traditional model taken by the Federal Communication Commission (FCC) to assign fixed frequency has ran into challenges in recent years as radio spectrum has now become increasingly scarce. The discipline of wireless communication has recently adopted a new paradigm called cognitive radio (CR), which enables a more efficient utilization of the Radio Frequency (RF) spectrum that is currently available. When there isn't a main user (PR) on the channel, cognitive radios (CRs) will also be able to use the spectrum to communicate with one another and interact with one another [24], [25], [26]. Spectrum sensing is the most important application for cognitive radios. By deploying highly developed spectrum sensing technology, the CR is able to identify the presence of authorized users of such airwaves (signal). In addition to this, it pinpoints the frequencies in the radio spectrum that are not being used. This chapter investigates a variety of approaches to the delivery of spectrum data.

Broad categories of spectrum sensing can be made based on the bandwidth, user count, detecting technique, and prior knowledge. All four of these elements are crucial to spectrum sensing. Techniques for spectrum sensing can be divided into two categories, narrowband and wideband, according on the bandwidth being used. Wideband sensing approaches concentrate on taking advantage of spectral possibilities over a wider frequency range, in contrast to narrowband sensing methods, which concentrate on taking advantage of spectral opportunities over a narrow frequency range. Spectrum sensing can be broken down into cooperative and non cooperative methods, with the former relying on a single user while the latter requires cooperation between multiple users. Spectrum sensing for non-cooperative systems, sometimes called local sensing or single-user sensing, manifests itself whenever a cognitive radio operates autonomously. While cooperative systems are sometimes referred to as "multi-user sensing" and their utilization by multiple users to gather spectrum information. Primary transmitter detection and primary receiver detection refer to the two possible points of spectrum sensing. Algorithms like Matched filter detection, Energy detection; cyclo-stationary feature detection, etc. are widely investigated and used for detecting transmitters. Spectrum sensing approaches can be broken down into "non blind," "semi blind and “blind" categories, depending on how much prior knowledge the detector has about the signal and noise. The information concerning the disturbance or primary user signals is irrelevant to the blind approach, which relies solely on the received signals. For a semi-blind method to work, either the additive noise variance or the primary cyclic frequency must be known in advance. Both the primary user signal and the noise variance are required for non-blind methods. In addition to these factors, the primary users' characteristics and the tradeoffs that arise among the various sensing parameters, such as the detection-probability and the false-alarm probability, play an important role in determining the best way to go about spectrum sensing. Few well known spectrum sensing methods are categorized as under and represented in the following figure 3.2.

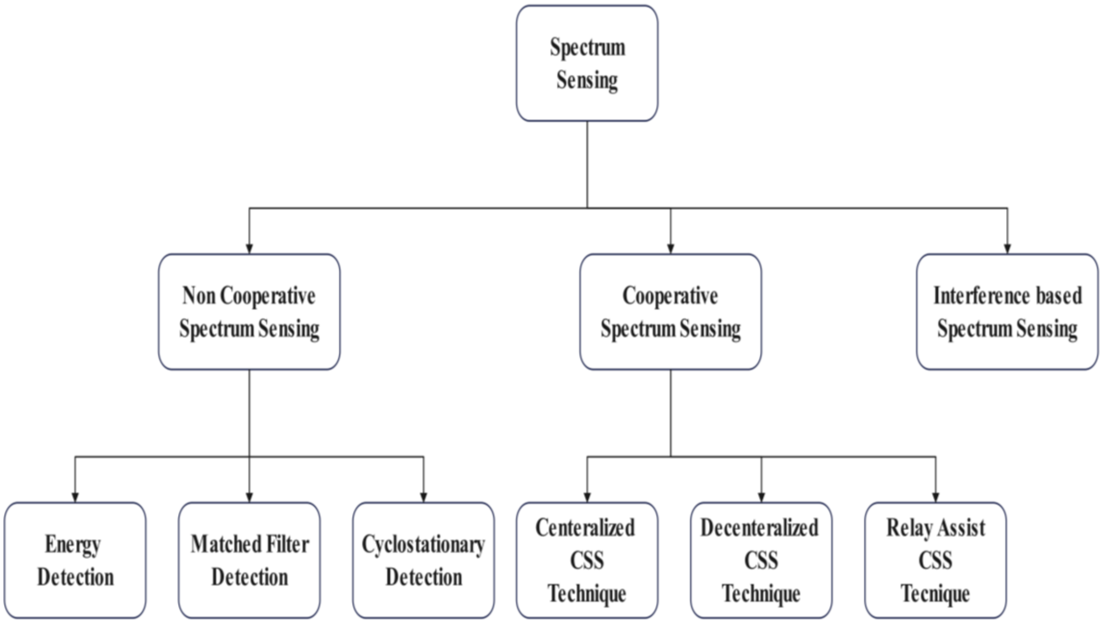

Figure 3.2: Classifications of Spectrum Sensing Methods

3.4.1 Energy Detection

When it comes to sensing the electromagnetic spectrum, this is one of the most widely employed methods. The standard energy detector works by calculating the amount of energy that is connected to the signal that has been received over a predetermined amount of time and bandwidth. After that, the value that was measured is compared with a threshold that has been carefully chosen in order to establish whether or not the primary user signal is there. Additionally, energy detector doesn't necessitate familiarity with the licensed user's signal settings. The energy detector method entails a two-stage process.

- Quantifying the detectable signal's power in a certain frequency range.
- Comparing the observed signal parameter (i.e., the received energy) to a preset threshold in order to determine whether or not PU is present in the spectrum.

The key objective here is to make a decision between the following two hypotheses: (H_0) there is no primary user signal present, and (H_1) there is primary user signal present. In order to arrive at its conclusion, the energy detector is putting the following hypothesis through its paces [25], [27], [30], [31]:

$$H_0: \quad y(n) = w(n) \tag{3.8}$$
$$H_1: \quad y(n) = h \cdot x(n) + w(n) \tag{3.9}$$

Where H_0 indicates that the primary user is not available and H_1 indicates that the primary user is available hence secondary user is trying to get another vacant spectrum in surrounded environment. While n is the total number of samples (n = 1,2,3….N), h is the complex channel gain of the sensing channel, and $w(n)$ represents the additive white Gaussian noise (AWGN) that has a mean of zero and a variance of δ_w^2.

Two time-domain variants of the classic energy detector are taken for theoretical evaluation:

Analog-Energy-Detector: A pre-filter, square-law device, and finite-time integrator make up the analog energy detector as shown in figure 3.3 [24], [27], [30], [31]. A pre-filter, it controls the noise's bandwidth and makes the noise more consistent. The outcome of an integrator is directly related to the strength of the received signal.

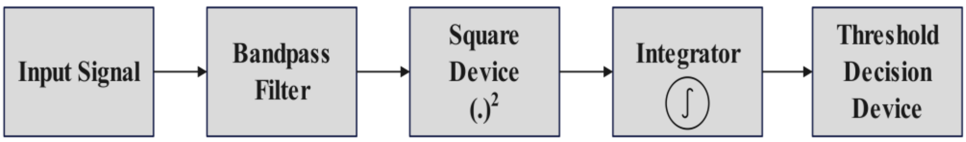

Figure 3.3: Time-domain block schematic of the Analog-Energy Detector

Digital-Energy-Detector: The components of a digital energy detector are shown in figure 3.4: a band pass noise pre-filter to reduce unwanted noise and adjacent-bandwidth signals, an analog-to-digital converter (ADC) to convert continuous signals to discrete digital signal samples, a square law device, and finally an integrator [26], [29], [31].

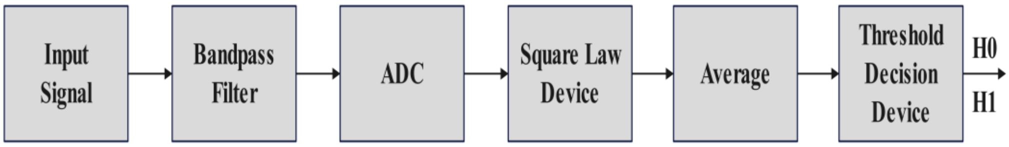

Figure 3.4: Time-domain block schematic of the Digital-Energy Detector

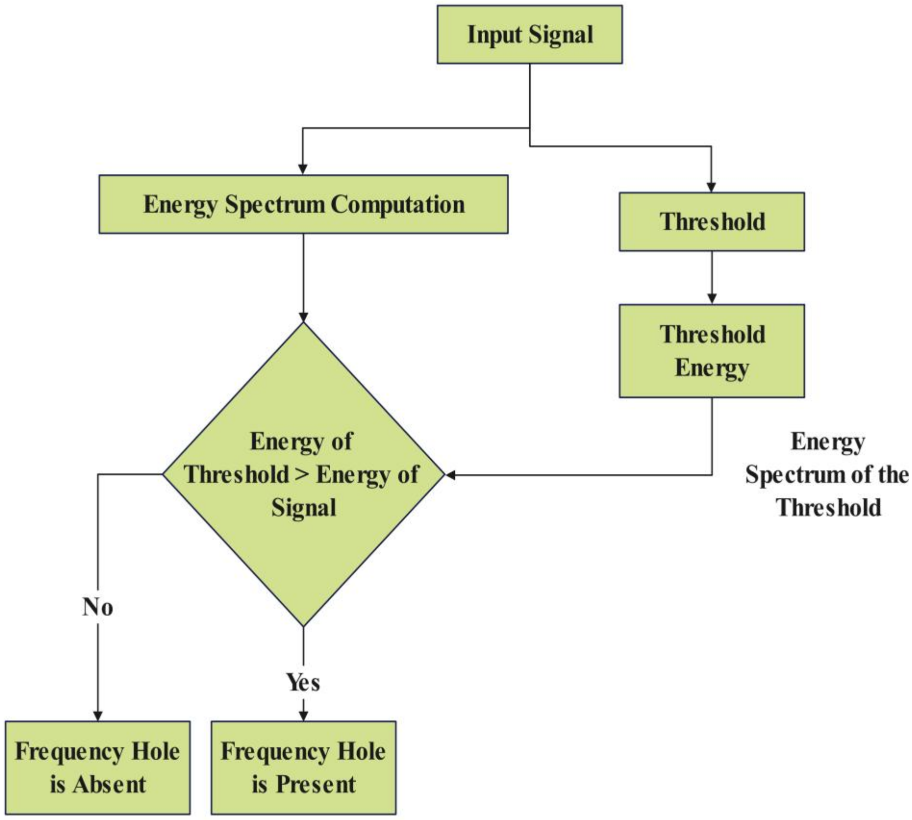

Figure 3.5: Diagrammatic Representation of the Energy Detection Process

The A/D converter's output is then squared and added up over a set amount of time. A test statistic is made from the signal that comes out of it. As shown in equation 3.10 the test statistic can be written as [23], [25], [27], [28] [31],[32].

$$T_{ED} = \sum_{n=1}^{N} |y(n)|^2 \tag{3.10}$$

Where n is the number of samples (detection period can be 0, 1, 2, 3,..., N). According to the central limit theorem [30], if N is large enough, the distribution of the T statistic will be Gaussian. Instead of the traditional binary hypothesis test is as modified as follows.

$$H_0 \ : T_{ED} \sim Normal\ (N\sigma_w^2 + N2\sigma_s^4) \tag{3.11}$$

$$H_1 \ : \ T_{ED} \sim Normal\ ((\sigma_w^2 + \sigma_s^2), 2N\ (\sigma_w^2 + \sigma_s^2))^2 \tag{3.12}$$

σ_w^2 is represents the noise variance while σ_s^2 is represents the primary signal's variance. T_{ED} is referred as testing metric and that values are compared with the pre-determined threshold (γ_D) for the energy detection as furnished under;

If $T_{ED} \geq \ \gamma_D$; Indicates the PU is exist (3.13)

If $T_{ED} < \ \gamma_D$; Indicates the PU is not exist (3.14)

For the measure the performance of the energy detector the benchmarks such as detection probability, false-alarm-probability and missed-detection-probability are expressed as under [26], [31], [32];

$$P_D = Q\left(\frac{\gamma_D - N(\sigma_w^2 + \sigma_s^2)}{\sqrt{2N\ (\sigma_w^2 + \sigma_s^2)^2}}\right) \tag{3.15}$$

$$P_{FA} = Q\left(\frac{\gamma_D - N(\sigma_w^2)}{\sqrt{2N\ (\sigma_w^2)^4}}\right) \tag{3.16}$$

$$P_{MD} = 1 - P_D \tag{3.17}$$

In the above expression 3.15 and 3.16, the function $Q(\cdot)$ represents the complementary distributed function of standard Gaussian. The expression of it is as follows [31], [33];

$$Q(z) = \frac{1}{\sqrt{2\pi}} \int_z^{\infty} \exp(-\frac{q^2}{2})\, dq \tag{3.18}$$

3.4.2 Matched Filter Detection

Local sensing can also be accomplished by either the use of energy detection or matching filter detection. In digital signal processing, a technique known as the "Matching Filter" is used; this consists of a succession of linear filters. The matched filter approach is vital in the realm of communication due to the efficient filtering method that it employs, which optimizes the signal-to-noise ratio (SNR) [37]. The output signal-to-noise ratio of the detector is enhanced by using a matched filtering strategy to achieve maximum results. It is used to optimize the signal-to-noise-ratio (SNR) when there is additive stochastic noise present. It provides the most accurate detection possible. It is the type of spectrum sensing techniques that is simultaneously the most accurate and the most difficult. The matching filter detection method cannot be utilized until all of the required details, including the pilot carrier, kind of modulation, dispersion codes, and pulse shape, are known [36], [38]. It is possible to differentiate between the major user of the channel and the many secondary users who also utilize it. Utilized here is the idea of cross correlation, which compares the signal which was received to the sequence that is already known. The presence of a signal from a principal user can be identified by a cross correlation peak that is positive; in the absence of this peak, the band is considered to be unoccupied. In addition, matched-filter detection is used to measure the power consumption of the primary user [40]. It is possible for the power level of the principal user to shift in response to changing circumstances. In order to combat the varying power levels of the licensed user and the interference, the unlicensed user should be able to modify its own power level while simultaneously monitoring the power level of the licensed user. As a result, the operation that is carried out by matched filter detection is functionally equal to a correlation. The signal that has been received is therefore convolved with the band pass filter, which is the replica of a reference signal that has been replicated and time-shifted.

Figure 3.6 depicts the system architecture of a matched filter detector (MFD) spectrum technique [35], [36], [37], [39], [41], [43]. A band - passes filter (BPF) picks the required range of a signal from the receiving inputs and eliminates the undesirable signal (band not taking an interest) from the incoming signal. An input signal that is received by CR users is combined with Gaussian-noise and then fed through the band-pass filter. In order to receive both the signal from the BPF and a reference signal that is out of sync in time, the matching filter must now be put into operation [37]. The matching filter's output must be assessed by comparison, the threshold must be chosen based on channel information, and the detection result must be acquired with the existence or non-existence of the PU depending on the threshold values.

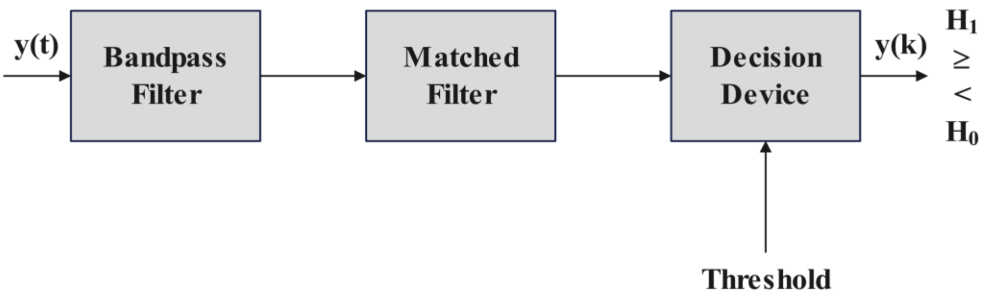

Figure 3.6: Block Diagram: Method of Detection Using a Matched Filter [42]

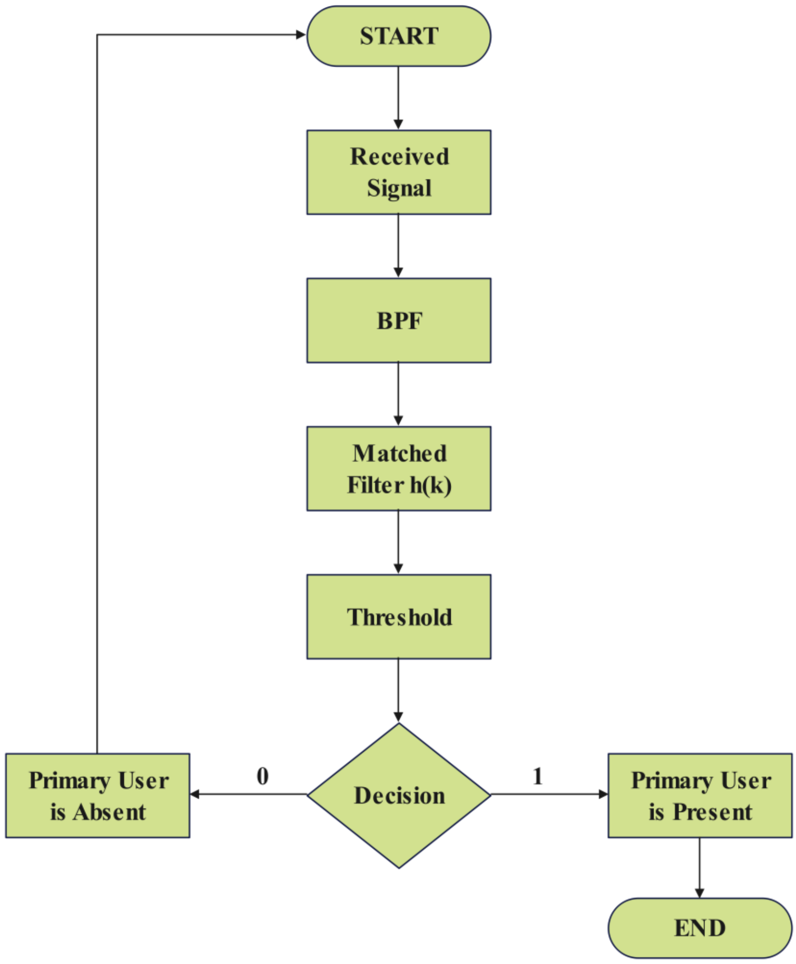

Figure 3.7: Diagrammatic Representation of the MF Detection Process [34]

3.4.3 Cyclo-stationary characteristics based detection

The modeling of data symbols typically involves depicting them as stationary stochastic processes. Nonetheless, transmitted signals are typically paired via carriers, spike patterns, repetitive patterns or cyclical prefixes, and other purposeful signals that generate concealed periodicity. This is done for a variety of reasons. Such transmitted signals are distinguished by a number of characteristics and are categorized as cyclo-stationary stochastic variables rather than stationary stochastic variables, which is how radiological techniques classify arbitrary methods. The cyclo-stationary detection is a parametric analysis that is dependent on the predicted autoregressive model from one or more observed cyclic frequencies. This test can be applied to a single cycle frequency or multiple cycle frequencies. Cyclo-stationary detection requires prior knowledge about the process one desires to discover besides the energy detection. From this point forward, cyclo-stationary detection will be able to detect a limited number of systems for which the communication signal procedures are aware of cyclo-stationary features; however, on the contrary side, such systems will need to be clearly and unambiguously recognized by the cyclo-stationary detection. Several efforts have been done which use such kind of detector towards the issue of spectrum access.

By taking use of the cyclo-stationary characteristics of the signals received, cyclic frequency domain (CFD) detection can be used to identify PU broadcasts. If the auto-correlation of a signal is a repeating response to time for several intervals, researchers say that the transmission is cyclo-stationary. Statistical parameters of realistic information, such as the mean and auto-correlation, repeat at regular intervals. Steady signals, on the opposite side, are randomized signals in which the physical characteristics don't really evolve over period. In contrast, cyclo-stationary processes emerge from synchronised groups of such a stochastic function, while stationary processes emerge from asynchronously choruses of the same process. When a transmission signal has a pattern that is repeated after a certain time frame, cyclo-stationary detection can use this to its advantage.

To locate the PU signal inside the spectra, cyclo-stationary feature extraction makes recourse to its cyclo-stationary characteristics. Metrics such as the signal's autocorrelation and mean change at regular intervals, this property is known as cyclo-stationary. Due to non - uniform and non-cyclo-stationary character of noise, such technique offers greater resilience to noise in the channel than any other spectrum sensing method. Utilizing variable named as cyclic autocorrelation function (CAF), cyclo-stationary properties could be derived out from signal.

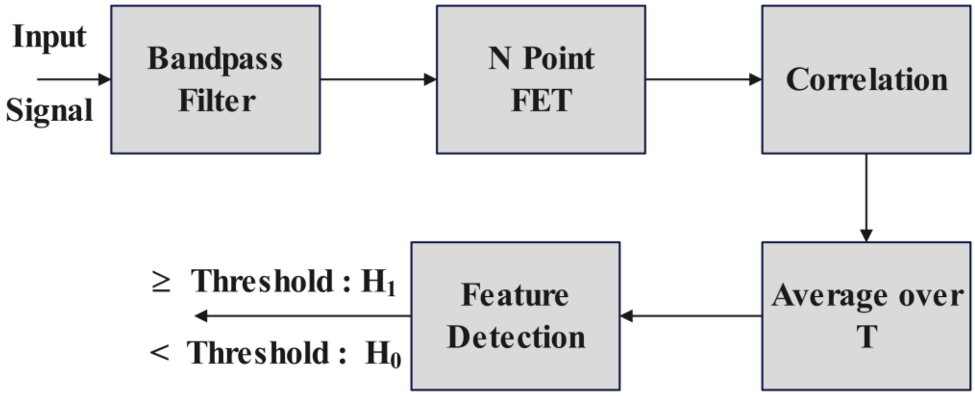

Figure 3.8: Block diagram of Cyclo-stationary feature based detector

A block diagram of CFD is depicted in figure 3.8 [44], [45], [46], [47]. As can be seen in above figure, the incoming received signal was first filtered from the band pass filter, and afterwards the Fast Fourier Transform is delivered to it using an N-point sequence number. Auto-correlation functions are employed to associate the incoming signal with a correlation function. In a broad sense, noises are non-repeating signals with zero mean and no periodicity of the second order. As a result, one can readily separate signal from noise by using technique. This is why cyclo-stationary detection is so resistant to background noise. Finding a peak and comparing it to a predetermined threshold allows one to deduce whether or not a primary signal is there amongst potentially distracting background noise. The flow chart for the cyclo-stationary featured based detection is given as under.

3.4.4 Interference based Sensing

Interference, which is something that has been a problem in wireless networks for a very long time, is one of the key indicators that can impair the functioning of wireless technologies. It is not at all an exaggeration to say that wireless communication is simply the battle against the degradation and congestion of communication networks. It is crucial to solve the interference problem in CR networks. That is, CR delivers on its core commitment of protecting the primary system from harmful influence. The structure of an interference temperature detection method allows for peaceful coexistence between CR users and PUs. Although CR users are permitted to transmit, they must do so with a modest power level to avoid disrupting PU signals. The maximum allowed power strength for the transmitter is defined by the stated restriction on the quantity of interfering that can occur. Above this threshold, interference becomes inevitable, which is obviously bad. As part of this method, cognitive radio users perform inside a frequency band overlay like that of ultra-wide-band (UWB). The fundamental principle of the UWB technology lies in how the device could share information with high bandwidth throughout a sizable chunk of the radio spectrum, so long as the energy expenditure for such communications is kept to an absolute minimum. [48], [49], [50].

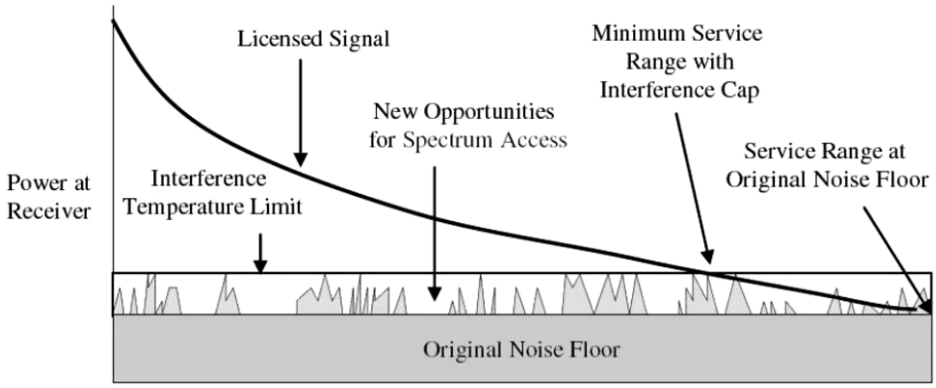

Figure 3.9: Model for Interference-Temperature Control [48], [49]

Figure 3.9 depicts the underlying paradigm of temperature-based interference detection. One of the issues with this strategy is that it can only provide so much juice. Even if the PU is turned off completely, the CRUs still can't send data at full strength. To prevent the disruption caused to other users' equipment, CRUs' power levels should stay below the set threshold. In order to prevent interference with PU communications, it's really crucial for CRUs to keep track of the location and the matching threshold level of allowable power level through that location all of the time.

Secondary users do make use of a variety of spectrum sensing methods, including waveform-based sensing and radio identification-based sensing, amongst others. The analysis of the similarities and differences between all of these various methodologies can be found in Figure 3.10.

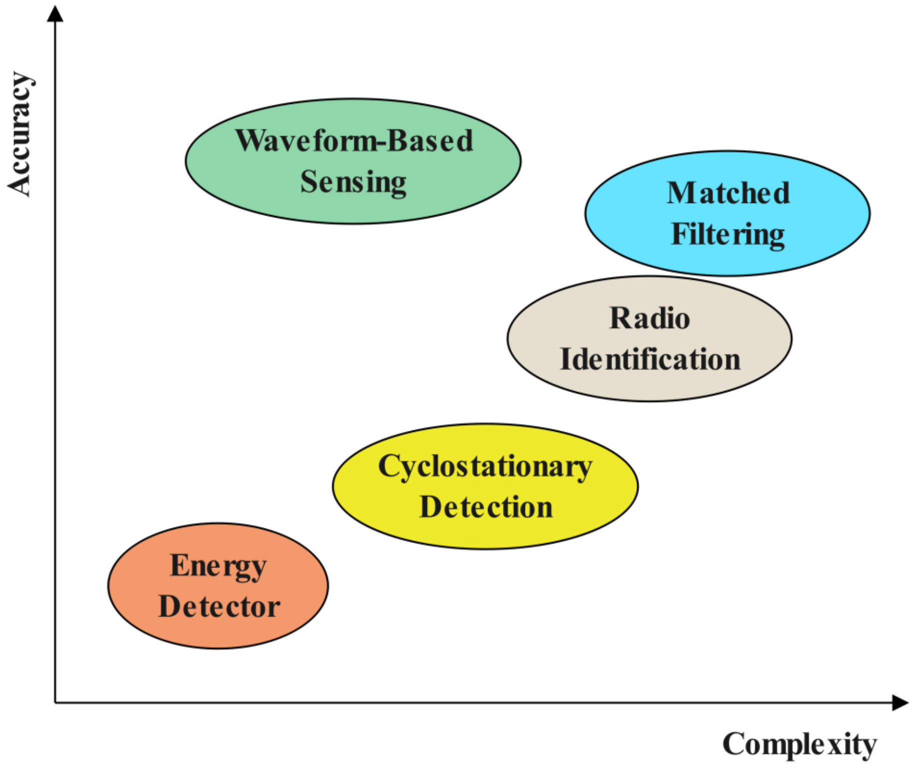

Figure 3.10: Comparative analysis of the reliability and complexities of several SS approaches

3.5 Channels for wireless sensor networks

The air interface is the medium throughout which wireless interaction takes place. From the sender to the receiver, the signal will make the journey along the path of transmission. One such course of action can be blocked by things in the proximity between the sender and receiver, as well as by things that change its electromagnetic energy at the received signal.

As a result, the signal that is received will get worse and become different from the signal that was sent. Since the wireless channels seem to be arbitrary, establishing them is mainly performed using statistics.

The different kinds of radio propagation building models are based on how the path changes. The changes caused by propagation loss as well as shadowing that happen over long distances are called "Large-Scale-Propagation." Small-scale-propagation, on the other hand, is the change caused by quick changes as well as beginning to fade beyond a short range or amount of time [52], [53], [54], [55].

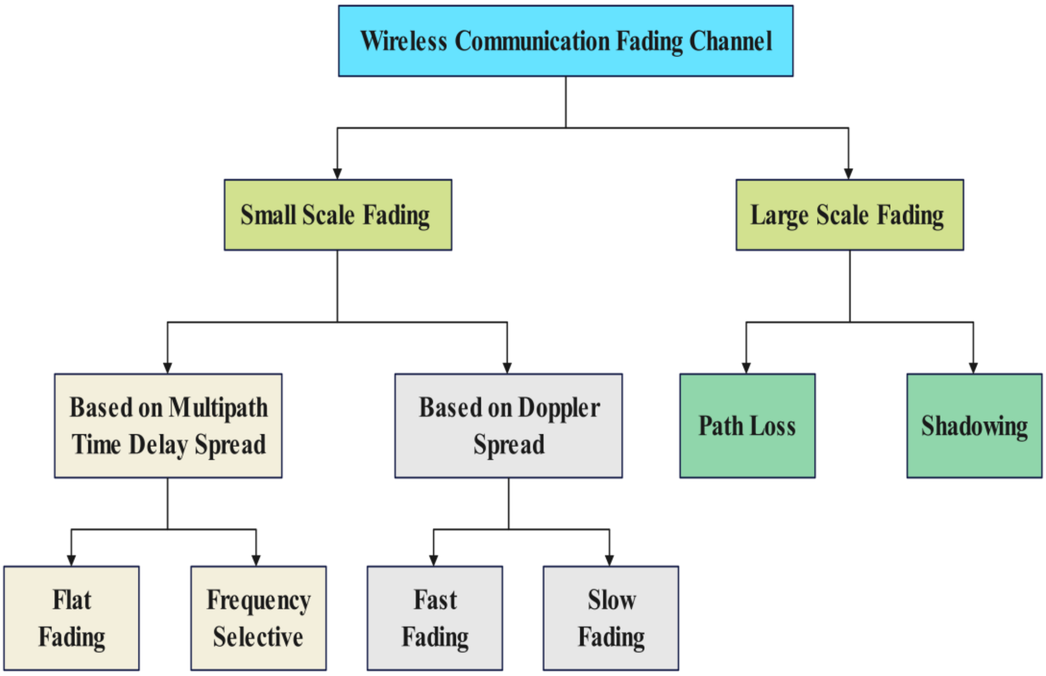

Figure 3.11: Classifications of wireless communication fading channel

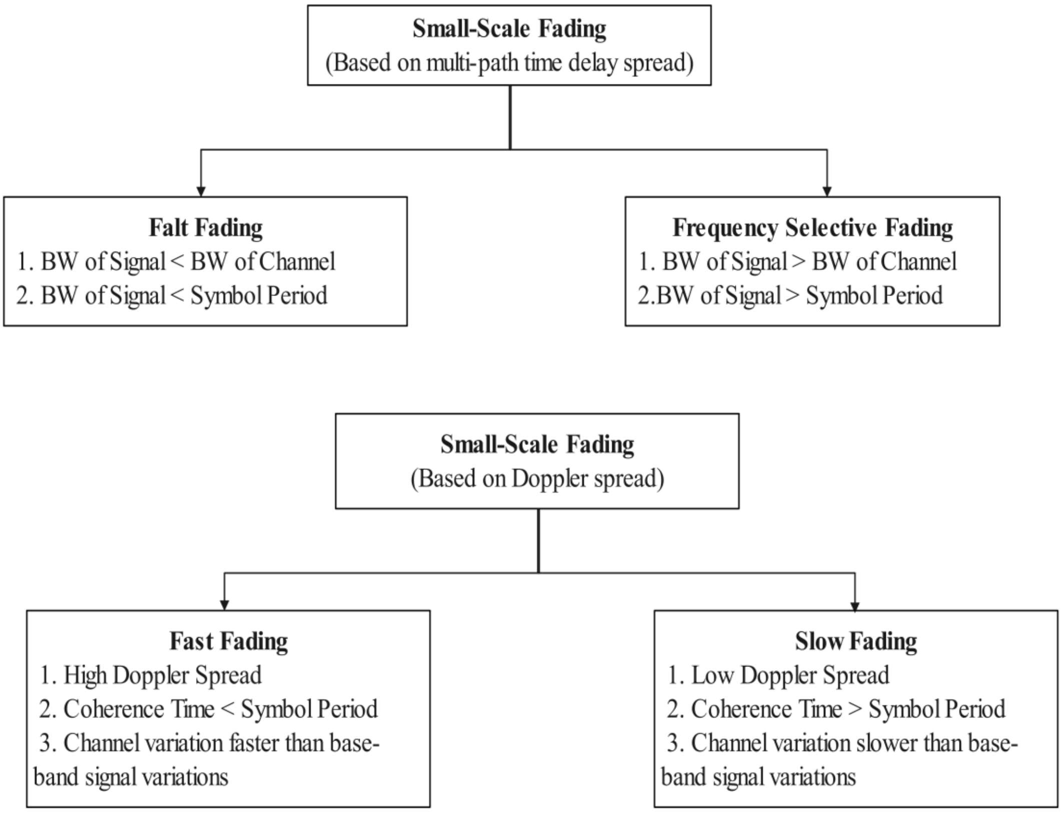

Figure 3.12: Classifications of small-scale-fading [52], [54], [55], [56]

3.5.1 The Effect of Radio Transmissions on Spectrum Sensing

In wireless communication networks, multi-path fading and shadowing are two natural processes (see Fig. 3.13) that reduce the dependability and intensity of receiving main user signals. Shadowing may also be caused by interference from other users. When electromagnetic radiation in free space travels from its source to its destination, it undergoes a phenomenon known as multi-path fading, which is sometimes referred to as small-scale fading. This phenomenon occurs due to the unexpected nature of the route taken by wireless communication. Attenuation of the propagating signals can make it harder to distinguish the principal subscriber signal when it reaches the receiver in a faded situation. Shadowing, also characterized as large-scale fading, is a phenomenon that happens when there are substantial physical barriers in the path from transmitter to receiver, reducing the likelihood of reliable signal reception at the receiver end. This situation, known as the concealed terminal dilemma, arises when the CR cannot identify the presence of the Primary user (PU), therefore it transmits its signal anyhow on the assumption that the PU is not present.

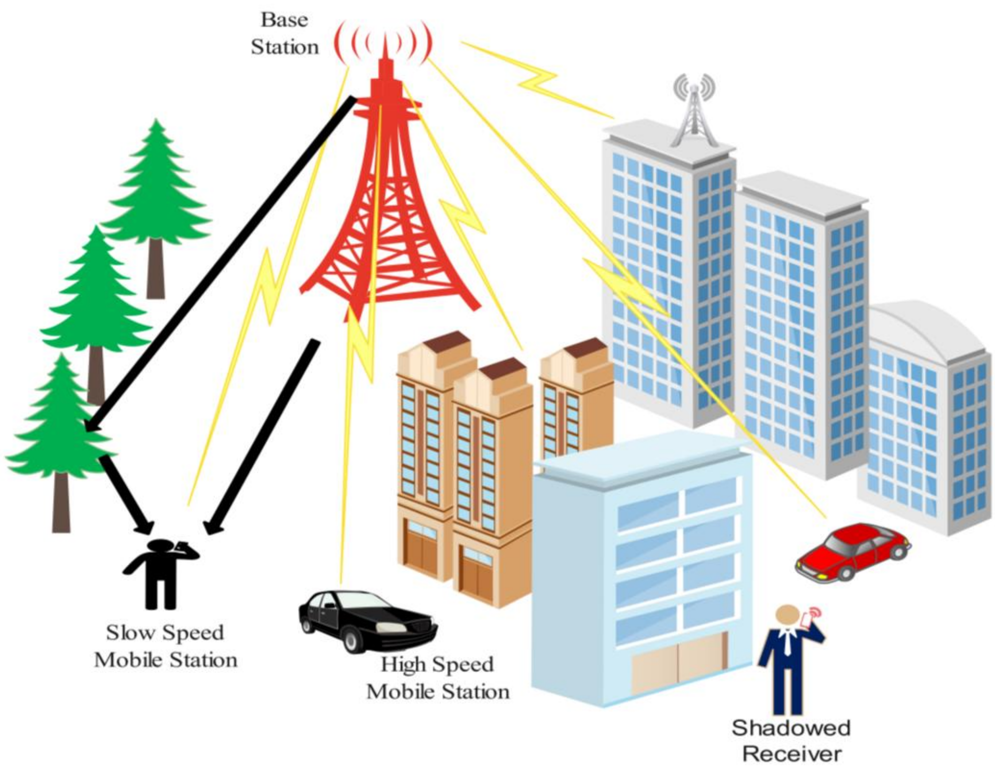

Figure 3.13: Common scenarios for wireless signal transmission

This obscured terminal issue and the resulting fading effect clearly depicted in Fig.3.13. The CR receiver uses the active channel and causes interference to the PU because it incorrectly guesses that the PU is out of range because it is obscured by high - rise building. Another CR receiver also suffers from fading because of a nearby tall structure and trees. The accuracy and precision of spectrum sensing are significantly impacted by these two factors.

3.6 Detection of Spectrum sensing over Fading Environment

In subsequent sub-section, the detection of spectrum sensing under various fading environment is discussed.

3.6.1 AWGN Channel

A real propagation model would be the additive white Gaussian noise (AWGN) channel model, which simply incorporates white Gaussian noise into the signal in a uniform manner. Energy detectors have a predetermined value, denoted by X, which is also known as the threshold energy. The X allows for examination of the three primary considerations such as detection probability, miss-detection probability and the false-alarm probability. The detection probability and miss-detection probability over AWGN channel is given as under [57], [58], [60];

$$P_{Detection} = P(T_{ED} > \gamma) \mid H1 \tag{3.19}$$

$$P_{False-alarm} = P(T_{ED} > \gamma) \mid H0 \tag{3.20}$$

In the above expression γ is the threshold value for the detection. The term $P_{False-alarm}$ is further represented as a probability density function (PDF) [58], [59],

$$P_{False-alarm} = \int_{\gamma}^{\infty} f_{T_{ED}}(t)\, dt \tag{3.21}$$

$$P_{False-alarm} = \frac{1}{2^d \Gamma(d)} \int_{\gamma}^{\infty} T_{ED}^{d-1} e^{-\left(\frac{T_{ED}}{2}\right)}\; dt \tag{3.22}$$

In the above expression, RHS is multiplied and divided by the 2^{d-1},

$$P_{False-alarm} = \frac{1}{2\Gamma(d)} \int_{\gamma}^{\infty} \left(\frac{T_{ED}}{2}\right)^{d-1} e^{-\left(\frac{T_{ED}}{2}\right)} \; dt \quad (3.23)$$

Now, $\frac{T_{ED}}{2}$ is replaced by t and limit of integration is changed from (γ, ∞) to $\left(\frac{\gamma}{2}, \infty\right)$;

$$P_{False-alarm} = \frac{1}{2\Gamma(d)} \int_{\frac{\gamma}{2}}^{\infty} (t)^{d-1} e^{-(t)} \; dt \quad (3.24)$$

or

$$P_{False-alarm} = \frac{2\Gamma(d, \frac{\gamma}{2})}{\Gamma(d)} \quad (3.25)$$

Where $\Gamma(\cdot,\cdot)$ is distinct by the incomplete gamma function.

Consequently, the detection probability can be represented with the help of Cumulative distributed function.

$$P_{Detection} = 1 - F_{T_{ED}}(\gamma) \quad (3.26)$$

From the above expression, the cumulative distributed function can be derived with the help of T_{ED} as under;

$$F_{T_{ED}}(\gamma) = 1 - Q_D(\sqrt{\lambda}, \sqrt{\gamma}) \quad (3.27)$$

Therefore using these above two expressions the detection probability over Additive-White-Gaussian-Channel is given as under;

$$P_{Detection} = Q_D(\sqrt{\lambda}, \sqrt{\gamma}) \quad (3.28)$$

In the above expression, the $Q_D(,)$ is the generalized Marcum_Q function.

3.6.2 Rayleigh Channel

If we want to know how the environment can affect a radio signal, like the kind used among wireless devices, we can use the statistical model described as Rayleigh fading. Assumptions made by Rayleigh fading concepts state that the amplitude of a signal after it has transited such a transmission medium (also known as a transmission medium) will fluctuate completely at random, or fade, based on a Rayleigh distribution, which is the radial element of the combined value of two stochastic random Gaussian variables. Rayleigh fading is widely accepted as a valid model for the transmission of radio-waves through the troposphere and ionosphere, as well as in densely populated metropolitan areas. If there is no dominant propagation along a line - of - sight among the receiver and the transmitter, Rayleigh fading is often beneficial. The Rayleigh fading effect is a phenomenon that occurs on a very small scale [60]. The fading will be placed on top of substantial environmental factors such as propagation loss and shadows. These parameters will be present.

The probability distributed function for the SNR ρ in these situations is given by the exponentially as [57], [59],

$$f(\rho) = \frac{1}{\bar{\rho}}\, e^{(\frac{-\rho}{\bar{\rho}})} \qquad ; \rho > 0 \tag{3.29}$$

The detection probability for such Rayleigh channel is found by averaging the corresponding probability-density-function with that of the AWGN channel.

$$P_{Detection\ Ray} = \int_0^\infty P_{detection}\ f(\rho)\, d\rho \tag{3.30}$$

Where, $P_{Detection\ Ray}$ denotes the detection probability for the Rayleigh channel. From the expressions 3.29 and 3.30 $P_{Detection\ Ray}$ is represented as,

$$P_{Detection\ Ray} = \frac{1}{\bar{\rho}}\int_0^\infty Q_D\left(\sqrt{2\rho}, \sqrt{\gamma}\right) e^{\frac{-\rho}{\bar{\rho}}}\, d\rho \tag{3.31}$$

In the above expression 3.31, $\sqrt{\rho}$ is replaced by x, ρ is replaced by x^2 and $d\rho$ is replaced by $2xdx$;

$$P_{Detection\ Ray} = \frac{2}{\bar{\rho}}\int_0^\infty x \cdot Q_D\left(\sqrt{2x}, \sqrt{\gamma}\right) e^{\frac{-x^2}{\bar{\rho}}}\, d\rho \tag{3.32}$$

The closure version for the detection probability, computed from the expression 3.29, is provided as the Rayleigh channels SNR (ρ) exhibits an exponentially distributed [57], [58], [59], [60].

$$P_{Detection\ RAY} = e^{\left(-\frac{\lambda}{\gamma}\right)} \sum_{n=0}^{d-2} \frac{1}{n!}\left(\frac{\gamma}{2}\right)^n + \left(\frac{1+\bar{\gamma}}{\bar{\gamma}}\right)\left[e^{-\frac{\gamma}{2(1+\bar{\gamma})}} - e^{-\frac{\gamma}{2}} \sum_{n=0}^{d-2} \frac{1}{n!}\left(\frac{\gamma}{2(1+\bar{\gamma}}\right)^n\right] \tag{3.33}$$

3.6.3 Rician Channel

Rician fading, also known as Rician fading, is a statistical model for wireless channel irregularity brought on by the tentative termination of a radio wave on its own. This happens when the signal is received by the receiver via multiple routes (hence indicating multi - path interruption), and at least one of these paths is in varies (expansion or reduction). Whenever one pathway is significantly more powerful compared to the rest, Rician fading happens. This is often the case with a line-of-sight signal or with certain strong reflection signals. A Rician distribution describes the amplitude gain in Rician fading. Since there is no direct line-of-sight between transmitter and receiver, Rayleigh fading can be seen as a specific situation of Rician fading. Although similar to Rayleigh fading, Rician fading has a much stronger dominating component [60]. In many cases, LoS is the primary factor. Two Gaussian random variables are used to simulate this, one having a zero mean while the other has a different mean.

Under the condition of the Rician fading, the probability of distributed function can be expressed as following [59] [63],

$$f(y) = \frac{2(k+1)y}{\bar{y}} \left[e^{-k-\frac{(1+k)y}{\bar{y}}}\right] I_o \left(\sqrt{\frac{k\,(k+1)}{k+1+\,\bar{y}}} \right.\;; y \geq 0 \tag{3.34}$$

In the above PDF expression, k denotes the ricean factor and mathematical expression is derived by taking averages of the detection probability over $f(y)$ in below expression [59], [63],

$$P_{Detection\ _{RIC}} = \int Q(y,\ \gamma) f_y\ (y)dx \tag{3.35}$$

$$P_{Detection\ _{RIC}} = Q\ \left(\sqrt{\frac{2k\bar{y}}{k+1+\bar{y}}}\ , \sqrt{\frac{y(k+1)}{k+1+\bar{y}}} \right) \tag{3.36}$$

3.6.4 Weibull Channel

Sudden shifts in the envelope of a received signal are referred to as small-scale fading. With the scattered approach and the presumption of a vast number of arbitrarily phased elements, the statistical of the receiving signal in a radio communication environment can be determined. If this is the case, the probability density function of the signal envelope follows a Rayleigh distribution. Weibull dispersion is also another distribution was using to describe fading in a multipath setting. This curve appears to have a perfect match to the empirical fading channel values, both indoors and outdoors.

The Weibull fading model is a straightforward fading model that is commonly utilized wireless technology. Another mathematical explanation of the statistical approach for characterizing amplitude fading in multi - path situations, especially those associated with mobile communications systems running in the 800/900 Mhz frequency range, is the Weibull channel [66].

The calculation of the corresponding PDF of the instantaneous SNR for every symbol is given by as follows [64], [65],

$$f_x(y) = \frac{b}{2}\left(\frac{\Gamma\left(1+\frac{2}{b}\right)}{\gamma'}\right)^{\frac{b}{2}} \gamma^{\frac{b}{2}-1}\, e^{-\left[\frac{\gamma}{\gamma'}\Gamma\left(1+\frac{2}{b}\right)\right]^{\frac{b}{2}}} \tag{3.37}$$

Where γ' indicates the average values of SNR / symbol.

In general, to express the detection probability of detection (P_d) under the weibull channel [64] and which is acquired from the expression 3.28,

$$P_{Detection\ Weib} = \sum_{m=0}^{n-1} \frac{\lambda^m\, e^{\frac{-\lambda}{2}}}{m!2^m} + \sum_{m=0}^{\infty} \frac{(-1)^m A^m \lambda^n}{1!m!2^n e^{\frac{\lambda}{2}} \gamma^{\frac{-ma}{2}}}^{m} \left(\Gamma \frac{ma}{2} + 1\right) F_1\left(\frac{la}{2} + 1, u+1, \frac{\lambda}{2}\right) \tag{3.38}$$

3.6.5 Two wave with Diffuse Power Channel

In M2M transmissions, the devices interact autonomously. The conventional M2M system consists of a large number of intelligent devices which can analyze information and carry out sensing tasks without even any human assistance. There is thousands of equipment in certain networks which are linked to each other in order to share the spectrum [67]. It means that the congestion is a real issue [68]. Unlike traditional systems, M2M networks are made up of wireless technologies because they are meant to be used in covered structures like high-rise buildings, transportation vehicles, etc. In these operational environments, there are many possibilities of fading conditions that the current model doesn't show [69]. The very worst scenario of fading in radio connectivity, as anticipated by such Rayleigh scenario, is observed in real-world deployments of sensing devices in metallic protective measure. Hyper-Rayleigh faded channels constitute the most common method of fading in this situation because of their small scale propagations.

The two-waves-with-diffuse-power model best describes this phenomenon. Fading caused by TWDP occurs in radio channels that have two waves of cons tant magnitude and a large number, smaller radio signals which are arbitrarily phases in reference to each other.

The meaningful mathematical description of a narrow-band local area containing magnitude of multi - path waveforms with respective accompanying phases that can be obtained by adding waves of constant amplitude and independent random phases can be found by performing the summing of these waves [70]. Through this stage, we can divide the components of this analysis into three distinct groups.

A specular element is a single term in this summation that represents single travelling multipath wave with a random phase. In this summation, a non-specular element is a set of 2 or many components that reflect more than single multi - path signal receiving toward the receiver. The diffused element is a non-specular element with many distinct waveforms, each having minimal power in contrast to the diffused element's total average power [70], [71], [72]. There are two factors that define this type of faded model. The proportion of specular to diffuse power (denoted by T) is the first parameter to be reviewed [71], [72], [73], [74].

$$T = \frac{Avg.Specualr\ power}{Diffused\ power} = \frac{{u_1}^2 + {u_2}^2}{2\sigma^2} \tag{3.39}$$

Where u_1 and u_2 are the voltage intensities of two reflected signals, and σ is the standard deviation. The second parameter, represented by the Δ, represent the ratio of the intensities of two reflected rays and it is represented by,

$$\Delta = \frac{Peak\ Specular\ power}{Avg.Specular\ power} = \frac{2u_1u_2}{({u_1}^2 + {u_2}^2)} \tag{3.40}$$

Under the TWDP fading environment, the probability of density function over signal-to-noise-ratio is expressed as [71], [72], [73], [74], [75].

$$PDF_{\gamma}(\gamma) = \frac{T+1}{2\gamma'} \exp(q_i) \sum_{j=1}^{k} q_i \left[\exp(q_i T) \exp\left(-\frac{(T+1)\gamma}{\gamma'}\right) A\right] + \left[exp(q_i T)\, exp\left(-\frac{(T+1)\gamma}{\gamma'}\right) B\right] \quad (3.41)$$

Where $\boldsymbol{\gamma}$ is instantaneous SNR and $\boldsymbol{\gamma'}$ is mean value of SNR, $\boldsymbol{q_i}$ denotes the approximation-coefficients.

3.7 Co-operative Spectrum Sensing

In a network of cognitive radios, secondary users (SUs) are present. CR users communicate and share primary users' prior knowledge with one another. When the primary users are not making utilization of the spectrum band, the secondary users can transmit using that available bandwidth. Secondary users will notify all other secondary users of the primary user's existence in the spectrum band if the secondary user detects the primary user. This type of sensing mechanism is referred as a Co-operative spectrum sensing (CSS). Co-operative spectrum sensing allows for maximum use of the available frequency band [76], [77].

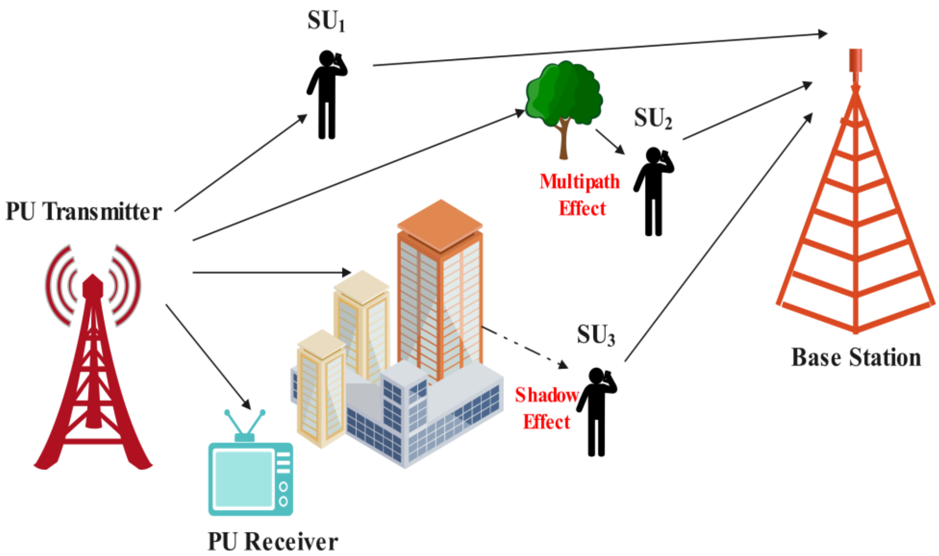

Figure 3.14: Effect of multi-path fading and shadowing effect in CSS

Take into account the scenario depicted in Figure 3.14, which includes both a primary system (consisting of a receiver and a transmitter) and a CR system (also consisting of a transmitter as well as a receiver). When the signal-to-noise ratio (SNR) falls under the CR transmitter's threshold limit, the SU3 transmitter is unable to pick up the primary transmitter's coverage. This could be due to significant fading or the fact that the SU3 transmitter is located beyond the existing communication range. As a result, the CR transmitter assumes the band is free and starts broadcasting upon that, which the existing receiver finds disruptive. The term "hidden node problem" is used to describe this phenomenon. When all of the secondary users are making utilize the exact same spectrum band, this might also lead to congestion between several secondary users. Both cooperation and non-cooperative methodologies can be used to address this issue and find a solution. Cooperative spectrum sensing is a method that can eliminate interference caused by shadow effect and multi - path fades [76], [77], [78], [79]. The primary purpose of using cooperative spectrum sensing is to minimize the amount of interruptions present such that detecting efficiency can be enhanced. However, the fact that a signal is not picked up by that of the sensing node doesn't often necessarily imply that it doesn't exist there. This is owing to the fact that perhaps the sensing node may well be experiencing a significant fade as a result of an obstruction in the geography. Spectrum sensing faces a significant challenge in the form of the hidden terminal challenge. Currently, researchers have been focusing a lot of their emphasis on attempting to resolve this terminal difficulty and minimize confusion in the sensing of the PU cooperative spectrum sensing system. In order for a single CR user to be capable of detecting wideband wireless spectrum, a significant amount of detecting time is required. On the other hand, these problems are solvable with the co-operation of different CR users. If we look at it from the view of such receiving device, the SNR of the detected existing signal is tiny due to fading channels and shadow effects, and it may be less than receiver's sensibility. The receiver's sensibility is its capacity to pick up on weaker signals, and greater sensitivity requires more complicated equipment, driving up the price. A particular limit imposed by the noisy ambiguity called the SNR barrier under where no signal can be detected, even if the receiver's sensibility is increased [78], [79]. Collaboration can reduce the necessary detection sensitivity, guarantee that it remains over the SNR wall, and bring it to a setting roughly equivalent to the actual propagation loss; this is known as the prospective cooperative advantage. In this scenario, secondary users in close proximity to one other work together to jointly sense the spectrum about a transmission of signals by the primary user (PU) by exchanging and comparing local sensing observations. Co-operative spectrum sensing strategies can be separated into two broad groups—centralized and de-centralized; depending on how users of cognitive systems exchange their sensed information [76], [77]. Through using these sensing channels, as demonstrated in figure 3.15, every cognitive user autonomously estimates the characteristics associated with their localized spectrum sensing. Then cognitive users make a binary choice in order to determine which one the primary user is within the licensed spectrum. Binary choices are transmitted to a universal receiver, also known as a Fusion center (FC), via the reporting channels in the system. The common receiver makes use of the results obtained from the secondary users. A determination is made regarding the existence of the primary user within the spectrum band according to the data that was obtained again from secondary users at the fusion center [78], [79].

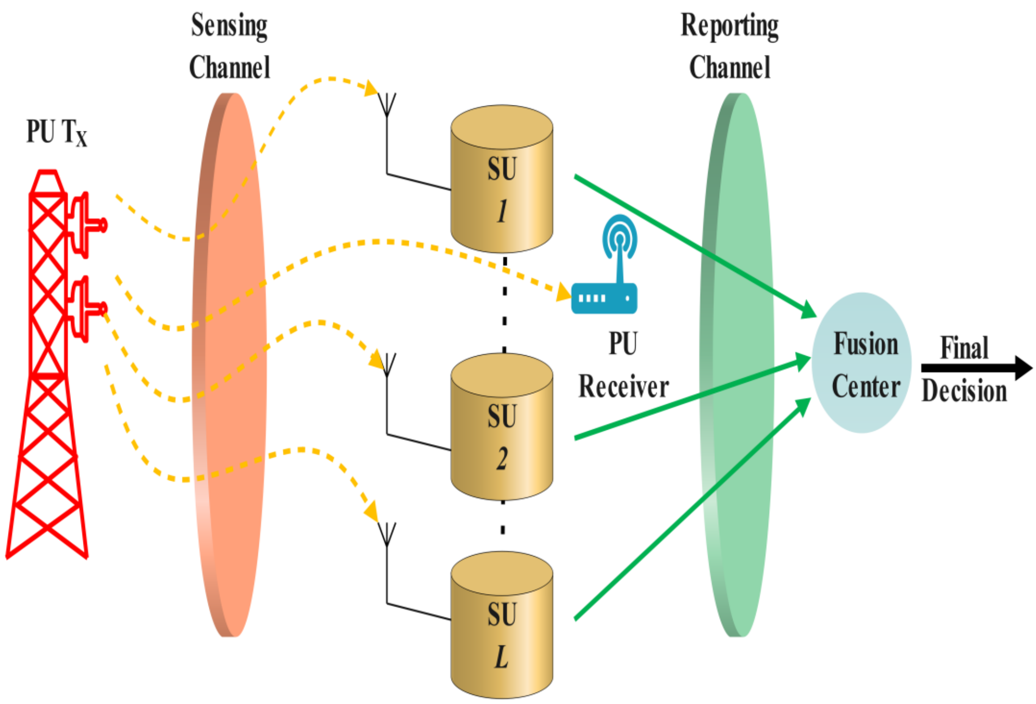

Figure 3.15: Fundamental working procedure of CSS

3.7.1 Co-operative Spectrum Sensing Model

Assume that L Cognitive user inside the cognitive radio system interact with one another in order to locate the PU. It ought to be assumed that every CR uses M samples from the received signal in terms of carrying out their own individual forms of localized spectrum sensing. The model of co-operative spectrum sensing model is depicted in the following figure 3.16.

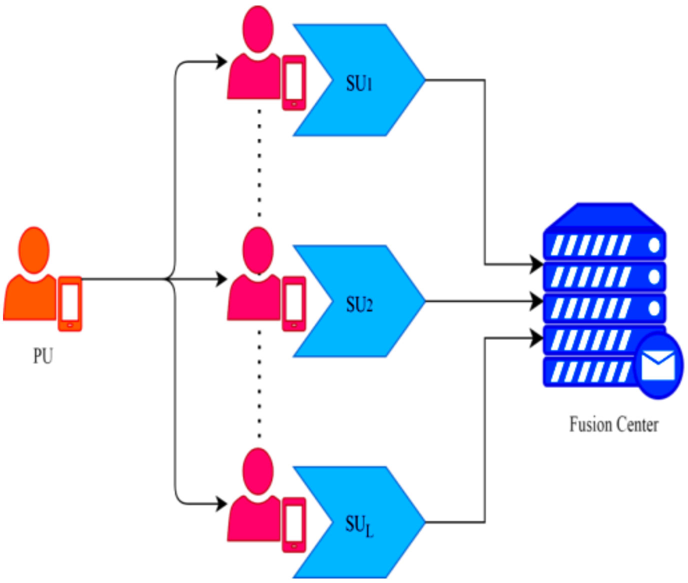

Figure 3.16: Co-operative spectrum sensing model

A binary hypothesis is capable of offering the following description of the sensing scheme [79], [84], [85]:

$$H_0 : Y_L(n) = w_L(n) \qquad L= 1,2,3\ldots l \qquad (3.42)$$

$$H_1 : Y_L(n) = h_L X(n) + w_L(n) \qquad L= 1,2,3\ldots l \qquad (3.43)$$

Where, $X(n)$ = Samples of PU signal

$w_L(n)$ = Noise with receive signal for L^{th} CR users

h_L = Complex channel gain linking PU and the L^{th} CR users

H_1 = PU is exist when channel is not available for CR networks

H_0 = PU is not exist when channel is available for CR networks

Using the Energy detection technique, the energy received for L^{th} CR user is expressed by the following expression [84],

$$E_L = \sum_{m=0}^{M} Y_L^2 \ (n) \qquad (3.44)$$

To make a one bit decision (1 or 0) the value of E_L is compared with the predetermined values of threshold γ_L,

$$\delta_L = \begin{cases} 1\,, & (E_L > \gamma) \\ 0\,, & (otherwise) \end{cases} \quad (3.45)$$

Detection probability for L^{th} CR users is expressed as following,

$$P_{D,L} = Prob\{\delta_L = 1\,|H_1\} = Prob\,\{E_L > \gamma_L\,|H_1\,\} \quad (3.46)$$

False-alarm probability for L^{th} CR users is expressed as following,

$$P_{FA,L} = Prob\{\delta_L = 1\,|H_0\} = Prob\,\{E_L > \gamma_L\,|H_0\,\} \quad (3.47)$$

If we consider $\delta_L = \delta$ for all CR users, therefore the detection probability, missed-detection-probability, false-alarm-probability can be expressed as under [85], [86], [87].

$$P_{D,L} = Q_{TB}\,\left(\sqrt{2N}, \sqrt{\delta}\right) \quad (3.48)$$

$$P_{FA,L} = \frac{\Gamma\left(TB, \frac{\delta}{2}\right)}{\Gamma(TB)} \quad (3.49)$$

$$P_{M,L} = 1 - P_{D,L} \quad (3.50)$$

Where, N = Signal-to-noise-ratio

TB = Time bandwidth parameter

Q_{TB} = Marcum Q_function

$\Gamma\,(\,.\,)$ = Complete gamma-function

$\Gamma\,(.\,,.\,)$ = Incomplete gamma-function

3.7.2 Classifications of CSS Model

In terms of appearance, there are two different ways to achieve Co-operative spectrum sensing (CSS), which are referred to as centralized CSS and de-centralized CSS [76], [77], [80], [81], [82], [88]. The primary users, the cooperating users, and the fusion-center that denotes the Point of access in the circumstance of a LAN Network or the Central Node in the scenario of a cellular connection make up the centralized CSS. In particular with respect to such components, the CSS methodologies employ two distinct kinds of wireless frequency channels for information exchange. Such connections are referred to as the sensing channel as well as the control channel. The sensing channel is the direct association that exists among the principle transmitter and every collaborative user. This link is utilized to monitor the primary signal. The control channel is the direct association that exists between the collaborative users and the FC. It is used to deliver the sensing results. Local sensing, report generation, and data fusion are the three principal stages that make up the entirety of the cooperative process that takes place amongst CR users.

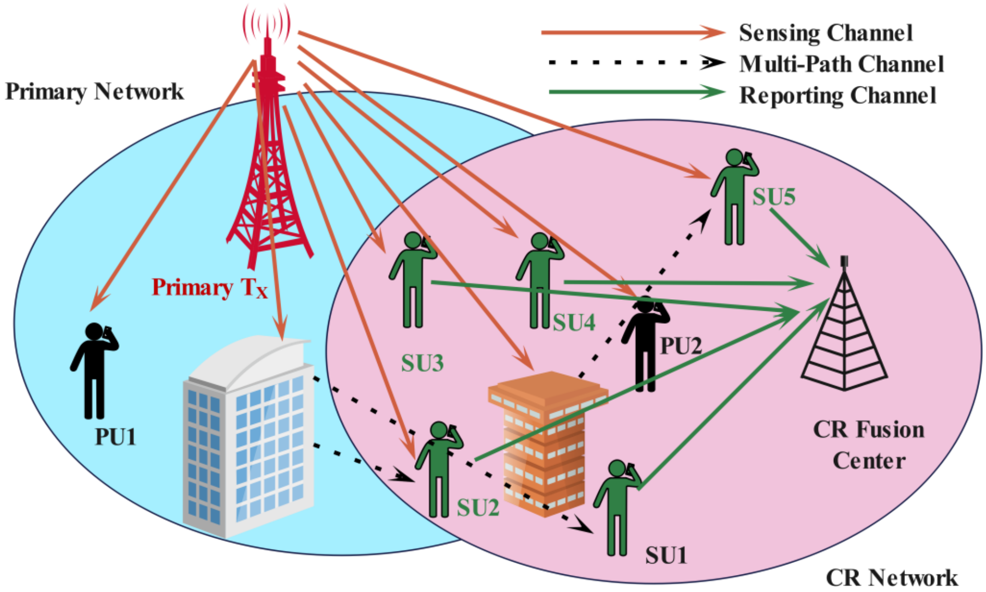

Figure 3.17: Centralized Co-operative spectrum sensing scenario

Centralized CSS, depicted in Figure 3.17, involves the FC deciding on some kind of channel that is important (sensing-channel) and afterwards requesting localized sensing from all collaborating users. As soon as they get the request, all cooperating users switch their wireless transceivers towards the chosen channel to monitor the primary signals. Then, all participating users will set respective wireless transceivers to the frequencies of control channel and begin reporting respective findings towards the FC. At last, the FC aggregates out all information's, makes a judgment to determine if a PU is available based on a proper data fusion algorithm, and broadcasts that call back to the Cognitive radios via the control channel [76], [80], [81], [82], [88], [90].

A de-centralized CSS architecture is made up of CR users alone; neither any FC is present [ ]. Towards this method, as shown in Diagram 3.18, every CR user does local sensing and subsequently communicates the sensed data to all other users. There are benefits to using a decentralized CSS system rather than a centralized one. The removal of costly communications infrastructure allows for much reduced installation costs, which is the main benefit. Another benefit of decentralized CSS is that it saves energy by allowing CR users to communicate with one another instead of with the FC, similar to the case in centralized CSS [76] [77], [80], [81], [82], [88], [90].

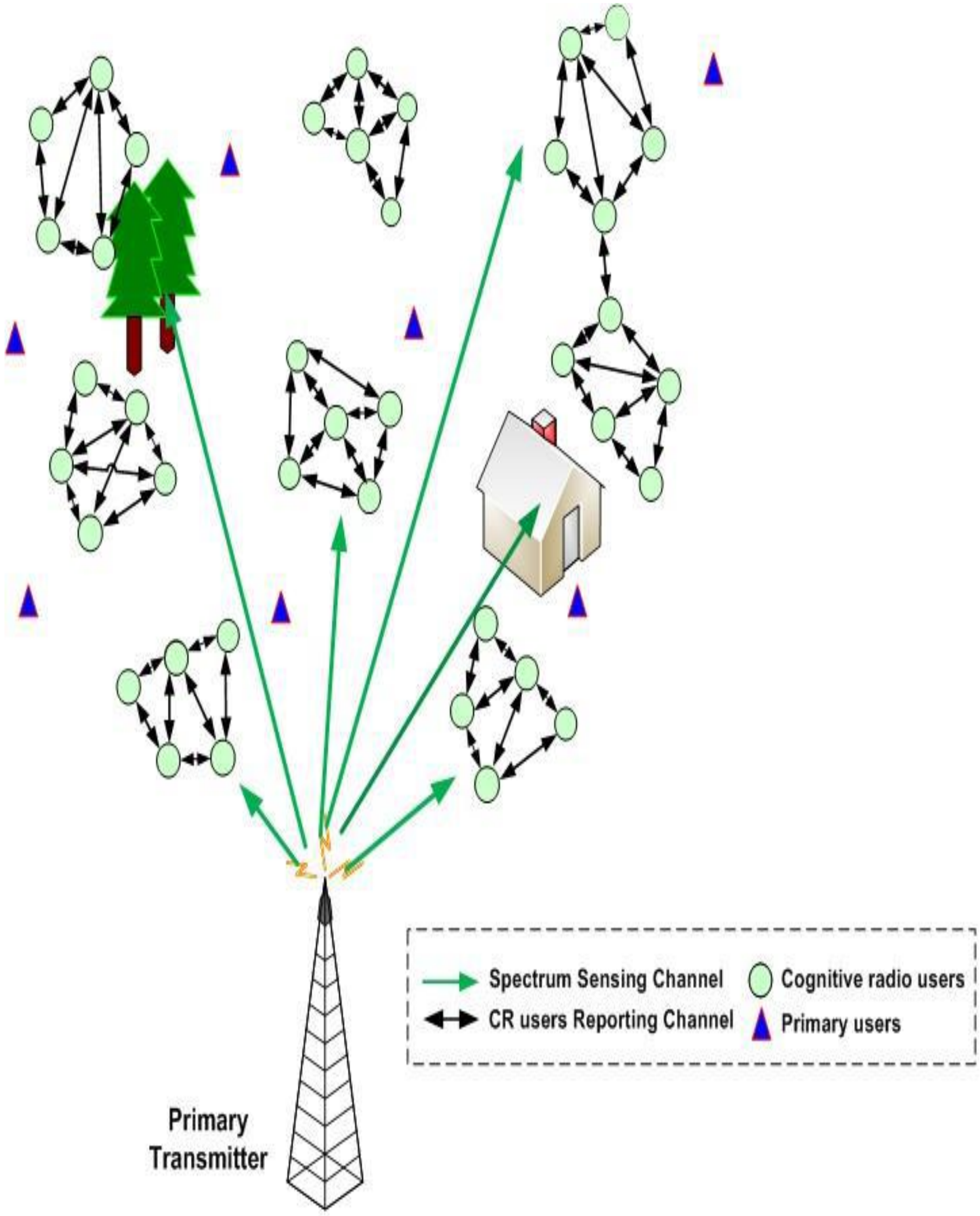

Figure 3.18: De-centralized Co-operative spectrum sensing scenario

Spectrum channels ought to be continuously examined in decentralized CSS to identify unoccupied channels for transmission. This demands that, CR users to share sensed information with one another, which could degrade the CRN's efficiency.

3.7.3 Data Combining techniques in CSS

Under the context of co-operative spectrum sensing, the process of merging the individually detected observations of separate secondary users is referred to as a fusion mechanism. In co-operative spectrum sensing, there are various information and decision fusion techniques that are determined by the different kinds of localized sensing observations by the participated secondary users in the network, that are sent to the central controller or fusion center via the reporting channel. Cognitive radio’s (SU) collaborate on the sharing of their precise local interactions as part of combined with soft decision strategy (Information fusion). Although in the strategy of data combining with hard decision strategy, is also known as decision fusion, cognitive radio (SU) simply shares the sensing decisions that are exclusive to each independent receiver [83], [87], [89], [90], [91], [94].

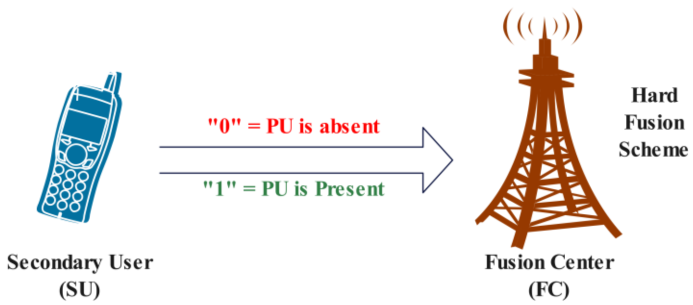

Figure 3.19: Data decision combining process in CSS

3.7.4 Hard Decision Strategy

With this kind of fusion strategy, each Cognitive user is responsible for determining if the PU is existent or missing and relaying their conclusion as a single bit (0 or 1) to the Fusion center. This implementation involves comparatively lesser amount of data transfer capacity or bandwidth than others, which is one of its principal advantages. The 0 and 1 logical decisions are employed in this process. They represent the presence and absence of PU, correspondingly. Whenever the binary choice has been communicated to the access point in FC, following are the main two significant rules that are utilized as the foundation for making the final decision.

AND Logic: In such fusion strategy, the judgment about whether or not a primary user signal is available which is made by the fusion centre (FC) based on whether or not all of the cooperating nodes for spectrum sensing identify the existence of a primary user signal. Fusion Center's judgment is analyzed based on the logical AND by each cognitive user's hard decision that they acquired from FC. As a consequence of this rule, the presence or absence of the PU can be determined based on whether or not all of the CR users delivered the one-bit decision as a "1" or a "0." One possible expression of this criterion is as follows:

$$H_1 \quad : \sum_{n=1}^{N} K_n = N \qquad (3.51)$$

$$H_0 \quad : Otherwise$$

From the above expression, the detection probability ($Q_{D_{AND}}$), false-alarm probability and missed-detection probability is evaluated using the following expression [86], [87], [89], [90], [91], [92].

$$Q_{D_{AND}} = \prod_{n=1}^{N} P_{D,n} \qquad (3.52)$$

$$Q_{PFA\_AND} = \prod_{n=1}^{N} P_{PFA,n} \qquad (3.53)$$

$$Q_{MD\_AND} = 1 - Q_{D_{AND}} \qquad (3.54)$$

OR Logic: In accordance with this criterion, the FC will reach the conclusion that the PU signal is available once it determines that one of the CR users has provided a one-bit judgment with a value of 1. The mathematical representation for this logic OR is given as following,

$$H_1 \quad : \sum_{n=1}^{N} K_n \geq 1 \qquad (3.55)$$

$$H_0 \quad : Otherwise$$

The mathematical expression for detection probability, false-alarm probability and missed-detection probability of this logic is given as under [86], [87], [89], [90], [91], [92].;

$$Q_{D\_OR} = 1 - \prod_{n=1}^{N} (1 - P_{D,n}) \qquad (3.56)$$

$$Q_{PFA\_OR} = 1 - \prod_{n=1}^{N} (1 - P_{PFA,n}) \qquad (3.57)$$

$$Q_{MD\_OR} = \prod_{n=1}^{N} P_{MD,n} \qquad (3.58)$$

3.7.5 Soft Decision Strategy

By following such fusion strategy, the FC receives sensing data from all CR users and does not require users to independently accomplish spectrum sensing in their local region. FC makes the decision by employing a set of combined rules. Square law combination (SLC) and maximum ratio combinations (MRC) are two of the most important combination rules used in these detecting methods. The decision's effectiveness is superior over that of the hard decision strategies, but only at the expense of channel capacity [91], [93], [94], [95], [96].

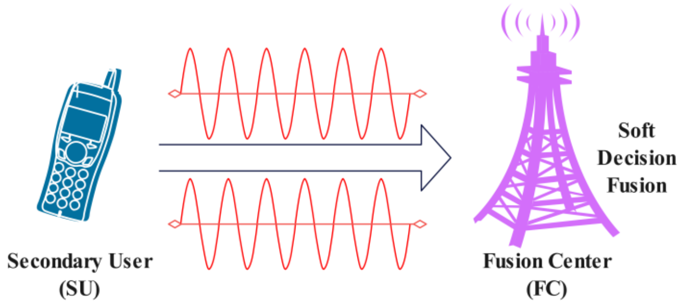

Figure 3.20: Soft data combining process in CSS

Square Law Combining: The computed energy at each secondary user is sent to the Fusion center, the results are added together, and the outcome is compared with a predetermined threshold to determine whether or not a PU is present. This is the most basic form of combination rule. The statistical mathematical expression of this rule is given by,

$$E_{SLC} = \sum_{n=1}^{N} E_n \tag{3.59}$$

Where; E_n is the received energy from the nth user.

The mathematical expressions of square-law combining for the detection-probability, false-alarm probability and missed-detection probability is given by, [91], [92], [93], [94], [95], [96].

$$Q_{D,SLC} = Q_{mn}\left(\sqrt{2\gamma'_{SLC}}, \sqrt{\Lambda}\right) \tag{3.60}$$

$$Q_{PFA,SLC} = \frac{\Gamma\left(nK, {}^{\Lambda}/_{2}\right)}{\Gamma(nK)} \tag{3.61}$$

$$Q_{MD,SLC} = 1 - Q_{D,SLC} \tag{3.62}$$

Where, $\gamma'_{SLC} = \sum_{n=1}^{N} \gamma_n$, γ_n is the received signal-to-ratio at nth the user.

Max. Ratio Combining: In this rule, the obtained energies through every CR user are multiplied with a specified normalized weight before being added, but in SLC, the energy being simply added together. This is the only difference between this rule and SLC. The weights that are allocated are determined by the SNR that has been acquired from each CR user. The statistical test equation is given by, [91], [92], [93], [94], [95], [96].

$$E_{MRC} = \sum_{n=1}^{N} w_n E_n \tag{3.63}$$

The mathematical expressions of Maximum-ratio-combining for the detection-probability, false-alarm probability and missed-detection probability is given by as under [92], [93], [94], [95],

$$Q_{D,MRC} = Q_m\left(\sqrt{2\gamma'_{MRC}}, \sqrt{\Lambda}\right) \tag{3.64}$$

$$Q_{PFA,MRC} = \frac{\Gamma(K, \Lambda/2)}{\Gamma(K)} \tag{3.65}$$

$$Q_{MD,MRC} = 1 - Q_{D,MRC} \tag{3.66}$$

Where, $\gamma'_{MRC} = \sum_{n=1}^{N} \gamma_n$, γ_n is the received signal-to-ratio at n^{th} the user.

3.8 Overview of Literature Survey

As part of a cognitive network, a single cognitive radio will scan through information from many frequency bands in order to identify unused frequencies. Cognitive radio must also keep an eye on all the different frequency ranges and step back from the empty spots when primary users need to reclaim their frequencies.

Spectrum sensing is the ability to measure, sense, and be knowledgeable of the factors relating to the radio channel attributes, accessibility of spectrum and transmit power, radio's functioning environment, interference and noise, user requirements and applications, accessible networks (infrastructures), and nodes, local policies, and other in-service limitations. By sensing the spectrum, the primary purpose of a CR is to identify the presence or absence of PU activity or to determine whether or not PU is present. CRs are actively searching the spectrum for areas where there are gaps. The usage of the spectrum by the PU will not be disrupted in any way by the CRs, since they will instead go on to use other frequencies. It is possible that there will be a break in the spectrum that the CRs will utilize for communication if the PU is not present.

Literature studies are an evolving process that I conducted throughout my course work duration. This chapter's primary goal is to provide necessary context for understanding co-operative spectrum sensing methods for cognitive radio. These studies' previous research evaluations may be split into six distinct phases. These phases' components, purposes, and conclusions of studies are all laid out in Table 3.1 below.

Matter of previous studies	Purpose of Study	Conclusion of Study
Phase -1 Concept of CR Networks	To become familiar with the concept of cognitive radio.	Thoroughly learn the fundamentals of what cognitive radio is all about.
Phase -2 Functions of CR Networks	To become familiar with the cognitive radio function i.e. – Spectrum Sensing	Detection of Unused spectrum means Spectrum sensing is the challenging tasks in CR network.
Phase -3 Methods of Spectrum Sensing	To obtain a knowledge regarding spectrum sensing methodology with its advantages and disadvantages	Challenges of hiding terminals, shadowed, and multipath fading can be solved with the use of a cooperative spectrum sensing approach.
Phase -4 Co-operative Spectrum sensing method	Investigating knowledge gaps in Co-operative Spectrum sensing and its present difficulties.	It is difficult to synchronize the decisions of individual SUs with other CRs and the fusion center. In addition, the proclamation of judgment is a difficult process.
Phase -5 Decision fusion schemes in Co-operative Spectrum sensing	To investigate the CSS data fusion technique in the interest of improving detection outcomes.	In CSS, more SUs boost detection probability, but cooperative SUs overhead rises. Hence, the secondary user throughput-reporting overhead trade-off becomes an essential study topic.
Phase -6 Clustering algorithm	Clustering is a popular method for scaling down and optimizing wide flat communication infrastructure.	There are several benefits to using cluster-based networks rather than flat ones. Greater reliability, Reduced latency, Fewer power consumption, Increased adaptability, Better collision avoidance, Optimizing Network Lifespan etc.

Table 3.1: Several phases in the literature review process

My systematic review has taught me the following points of cognitive radio, and it has been gathered through a survey of relevant methodological literature:

- The theory behind cognitive radio networks
- Functions related to Cognitive radio towards the solutions of spectrum scarcity.
- Different spectrum sensing approaches, its advantages, disadvantages and limitations.
- Most challenging aspects of Co-operative Spectrum Sensing
- Strategies to address the deficiencies in Co-operative Spectrum Sensing over different fading environments
- The ideas behind cluster-based methodological approach to improve the performance of the system
- Figure out the clustering approaches to discover the correct solution.
- The solution is found by running a simulation in MATLAB with selection of appropriate MATLAB toolboxes.

A comprehensive literature review of cooperative spectrum sensing methods, types of decision approach over different fading environments is provided below.

Ahmed et al. [98] discussed the functionalities of cognitive radio networks as well as summarized the key points related to spectrum sensing techniques with its advantages and challenges. In order to function properly, Cognitive Radio devices must be able to detect primary users anywhere inside the primary network's coverage region. Hence, there are several obstacles and hurdles, especially in practical applications. Problems associated with spectrum sensing includes some key points such as, It requires high-performance hardware, Concealed primary-user issue, Methods of combining individual judgments for use in group detection, Primary user (PU's) identification in spread spectrum is crucial, and it may only require a small signal-to-noise ratio (SNR), Power variations in a transmission may be caused by multipath fading, Uncertain detection due to temporal dispersion, Because of the background noise, detection accuracy may suffer.

Munpreet et al. [99] explains why we require the cognitive radio spectrum and where it came from. This study details many different spectrum sensing approaches that may be implemented using a cognitive radio network. In addition to describing various spectrums sensing method, the study also discusses the benefits and drawbacks of each. There is currently a great deal of study that is needed to acquire the ideal sensing technique, since one way seems to be effective under some situations while another looks to be effective for other ones. In addition, there's a wide number of issues connected to the actual deployment of cognitive radio that need to be carefully handled and fixed.

Kanwaljeet et al. [100] investigated Cognitive radio's spectrum sensing techniques are in detail. It compares and contrasts the pros and cons of various spectrum sensing approaches. In contrast to non-cooperative sensing approaches, cooperative spectrum sensing methods are superior for spectrum sensing.

Tarangini et al [101] explains number of problems with non-cooperative spectrum sensing, often known as signal detection by a single user. Wireless channels have a number of disadvantages, such as shadowing and fading and noise unpredictability. As a result of these drawbacks, a novel approach dubbed Cooperative Spectrum Sensing (CSS) has been proposed in their study. Traditional spectrum sensing methods are compared in this study, and an appropriate sensing method, i.e. energy detector approach, will be chosen based on computing complexity, accuracy, and performance of the approximation. In this paper, they focus on improving on CSS that relies on traditional energy detection, In the CSS fusion centre, soft combining and hard combining are the two fundamental data combined methods employed. Due to its ease of use, the hard combining approach has risen in prominence; this method involves three significant rules: the AND condition, the OR condition and the MAJORITY rule. With hard combining, just the results of the hypotheses will be forwarded to the fusion center, which will then determine whether or not the primary user is present. They have factored in the false alarm rate and network control function for improvement.

Chen Guo et al. [102] proposed a cooperative sensing approach based on clusters in order to cut down on sensing's latency and overhead, this research. An important conflict between the quantity of clusters and the detection performance in the cognitive radio network, since such sensing accuracy may also be compromised even when a single cluster contains too many cooperative users. The best quantity of clusters could be determined by framing the dilemma as an optimal control problem. The simulated results validated the approximated optimal cluster count that is also determined.

Wang et al. [103] provided a thorough introduction to the field of cooperative sensing systems that are based on a clustering principle. Next, they presented some of the most essential ideas about sensing efficiency and sensing load. Furthermore, they categorized the sixteen plans into three groups based on their goals and provided in-depth analysis of each. Even though the varied spectrum surroundings of a huge CR network are taken into account by only a small fraction of the available systems, clustering remains an underdeveloped area. A decentralized system has greater adaptability and stability than a centralized one.

Dengyin at el. [104] proposed the conventional cluster-based cooperation spectrum sensing algorithms solely connect judgment threshold with false-alarm likelihood. Each CH performs data fusion using a basic OR-rule, which restricts sensing performance. This study proposed an efficient cluster-based CSS technique. Channel decisions affect judgment thresholds, improving local sensing. The cluster head uses the half-weighted fusion rule to handle detection performance in accordance with user dependability. Evaluating and simulating show here that enhanced technique improves spectrum sensing performance over the conventional algorithm.

Muskan at el. [105] reviewed CR network clustering strategies with its goals, pros, and cons. Each strategy uses many selection measures to find the cluster head in each cluster. Deployment and expected features determine a clustering technique. Nevertheless, few CR networks have addressed a considerable quantity of CRs, along with those who sacrificed latency, reliability, and service quality. Hence, several CRs and the compromise between parameters remain important.

Ebrahim at el. [106] improved CSS’s number of nodes to enhance SUs throughput. To determine effective capacity, they assume each SU negotiates among several SUs in its radio range in 1 symbol. Every SU broadcasts its sensing choice towards the cluster with this minimal overhead. Whenever the volume of SUs is considerable, negotiating performance is evident, so raising cooperative cluster size does not enhance effective performance. This research estimated effective performance as a function of cooperation number of clusters and finds the ideal cluster size to optimize performance. Mathematical findings reveal that the OR-rule reduces the optimum cooperation cluster size.

Giriraj at el. [107] proposed a D_CSS using clustered over Nakagami channel model. C_CSS is described with several fusion rules, and then efficiency is contrasted with cluster-based distributed CSS with 4 proposed approaches. Simulations demonstrate that distributed CSS's OR–OR fusion rule beats the others and centralized CSS.

Tingting at el. [110] explored a complicated heterogeneous CRN by taking into account all relevant aspects, In contrast to the standard CSS model. For the purpose of simulating the various degrees of fade and shadowing felt by each SU, they incorporated a path-loss component and noise ambiguity. They also looked into a dynamical grouping-based fusion algorithm, assuming that every SU experiences channel circumstances. In light of PU & SU motion, a strategy for dynamically combining groups depending on their locations has been developed. The adaptability and interoperability of the fusion rule are considerably enhanced by the use of dynamically groupings. Furthermore, various criteria weights would be applied to SUs in disparate groups in order to complete the data fusion process. For the DGF to work, the FC requires gathering only the decision result of every collaborative SU, which significantly cuts down on transmitting data and processing load. The suggested technique outperforms state-of-the-art solutions while significantly reducing the price of collaboration, as demonstrated by the simulated data.

Rahul at el. [111] discusses that due to small scale fading, traditional fading models are unable to efficiently monitor these communication conditions. Millimeter wave behavior in fading scenarios is modeled by the recently developed fluctuating two ray fading channel. Sensing the spectrum using ED is investigated here under FTR fading conditions. Spectrum sensing based on cooperative detection outperforms ED-based sensing under FTR fading conditions.

Erich at el. [112] discussed with the use of model selection and hypothesis testing, they demonstrated that TWDP fading accounts for the characteristics of the millimeter-wave channels found inside buildings. The specular components have more energy than expected by the Rician fit. A probable cancellation of two specular waves is accounted for in the TWDP fading fit. They argue that the TWDP fading model better captures the characteristics of mm-Wave interior channels based on this information. Also, this model's adaptability allows for the same channel model to be used to get Rician-fading ($\Delta = 0$) and Rayleigh-fading ($K = 0$) results.