A SMART SPECTRUM MANAGING MECHANISM FOR COGNITIVE RADIO NETWORKS

D.David Neels Ponkumar
Head of the Department, Dr. Sivanthi Aditanar College of Engineering, Tiruchendur,
david26571@gmail.com

ABSTRACT
Spectrum is a very valuable resource in wireless communication systems, and it has been a focal point for research and development efforts over the last several decades. As the demand of radio spectrum increases in past few years and licensed bands are used inefficiently, improvement in the existing spectrum access policy is expected. Cognitive Radio (CR), which is one of the efforts to utilize the available spectrum more efficiently through opportunistic spectrum usage, has become an exciting and promising concept. One of the important elements of Cognitive Radio is sensing the available spectrum opportunities. Dynamic spectrum access is expected to resolve the spectrum shortage by allowing unlicensed users to dynamically utilize spectrum holes across the licensed spectrum on non-interfering basis. This research is aimed towards the detection and classification of primary user's waveform in Cognitive Radio (CR) networks. The primary requirement of a spectrum sensing system is its real time processing and decision making capability. The simulation of CR system is used to detect the presence of primary user by avoiding interference. Spectrum sensing is a process to detect the spectrum holes (unused bands of the spectrum) providing high spectral resolution capability. Secondary users are allowed to operate at the vacant spectrum bands allocated to the Primary users. CR spots the spectrum holes and the idle state of the primary users to exploit the free bands and also promptly vacate the band as soon as the primary user becomes active. The simulation result using MATLAB show how the Cognitive Radio (CR) work with five users and how a secondary user uses a unused band. Assigning attenuation and detection of false alarms and probability of missed detection are also done.

1. Introduction to Cognitive Radio (CR)

With the recent boom in personal wireless technologies, the unlicensed bands have become crowded with everything from wireless networks to digital cordless phones. To combat the overcrowding, the FCC has been investigating new ways to manage RF resources. The basic idea is to let people use licensed frequencies, provided they can guarantee interference perceived by the primary license holders will be minimal. With advances in software and Cognitive Radio (CR), practical ways of doing this are on the horizon. Cognitive Radio (CR) can smartly sense and adapt with the changing environment by altering its transmitting parameters, such as modulation, frequency, frame format etc.

Cognitive Radio is defined as a radio that can change its transmitter parameters according to the interactions with the environment in which it operates. Cognitive Radio (CR) is an intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world), and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g., transmit-power, carrier-frequency, and modulation strategy) in real-time, with two primary objectives in mind:

1. highly reliable communications whenever and wherever needed
2. efficient utilization of the radio spectrum

2. Characteristics of Cognitive Radio (CR)

Cognitive Radio (CR) differs from conventional radio devices. Cognitive Radio (CR) can equip dynamically the frequency of operation and also adjusts its transmitter parameters. The main characteristics of Cognitive Radios (CR) are Cognitive Capabilities and Reconfigurability.

Cognitive Capability refers to the ability to sense and gather information from the surrounding environment, such as information about transmission frequency, bandwidth, power, modulation etc. With this capability, Secondary Users (SU) can identify the best available spectrum. Reconfigurability is the ability to rapidly adapt the operational parameters according to the sensed information in order to achieve the optimal performance. By exploiting the spectrum in an opportunistic fashion, Cognitive Radio (CR) enables Secondary Users (SU) to sense which portion of the spectrum are available, select the best available channel, coordinate spectrum access with other users, and vacate the channel when a Primary User (PU) reclaims the spectrum usage right. [2].

3. Cognitive Cycle

Cognitive cycle is shown in the following figure and its basic blocks are explained in the following paragraphs.

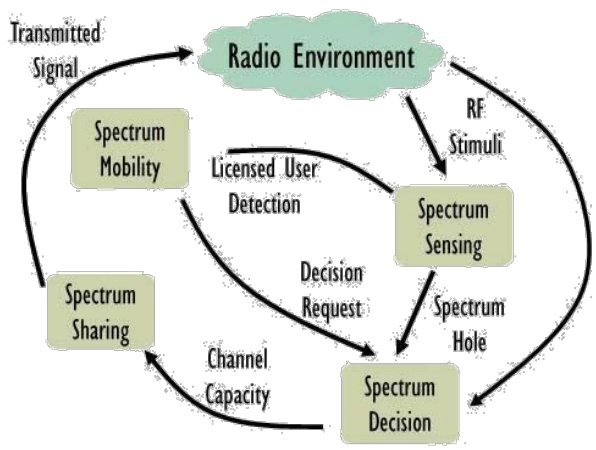

Figure 1Cognitive Cycle

3.1 Spectrum Sensing

Spectrum Sensing enables the capability of a CR to measure, learn, and be aware of the radio's operating environment, such as the spectrum availability and interference status. When a certain frequency band is detected as not being used by the primary licensed user (the unused spectrum is known as the spectrum hole or white space) of the band at a particular time in a particular position, Secondary User (SU) can utilize the spectrum, i.e., there exists a spectrum opportunity.[2]

3.1.1 Information gathering of Spectrum Sensing

In order to design an intelligent wireless communication system, Cognitive Radio (CR) is able to sense and be aware of its surroundings which make Spectrum Sensing an ideal requirement to realize. In wireless communications, radio spectrum is referred to as lifeblood. The unlicensed user, with the help of Spectrum Sensing can sense the environment to detect the unused spectrum. Spectrum Sensing is in need of various information before a decision is taken, which involves which part of spectrum it should sense & how, its bandwidth of spectrum of interest, when to sense and to see any priori information is available or not. It involves various steps which finally help in making a decision of the presence of primary user.

3.2 Spectrum Management

Spectrum Management provides the fair spectrum scheduling method among co-existing users. The available white space or channel is immediately selected by Cognitive Radio (CR), if once found. This property of Cognitive Radio (CR) is described as spectrum management. Spectrum Sensing, spectrum analysis, and spectrum decision fall in spectrum Management. Spectrum Sensing has been discussed in previous section. Spectrum Analysis makes possible the characterization of different spectrum bands, which is exploited to get the spectrum band appropriate requirements of the user. Spectrum decision refers to a Cognitive Radio (CR) decides the data rate, determines the transmission mode, and the transmission bandwidth. Then, the appropriate spectrum band is selected according to the spectrum characteristics and user requirements. [4]

3.3 Spectrum Sharing

Cognitive Radio (CR) assigns the unused spectrum (spectrum hole) to the Secondary User

(SU) as long as Primary User (PU) does not use it. This property of Cognitive Radio (CR) is described as spectrum sharing. The access technology of the Secondary Users (SU), licensed spectrum sharing can be further divided in two categories. They are Spectrum Underlay and Spectrum Overlay

3.3.1 Spectrum Underlay

In Spectrum Underlay, Secondary Users (SU) are allowed to transmit their data in the licensed spectrum band when Primary Users (PU) are also transmitting. The interference temperature model is imposed on Secondary Users (SU) transmission power so that the interference at a Primary Users (PU) receiver is within the interference temperature limit and Primary Users (PU) can deliver their packet to the receiver successfully. Spread spectrum techniques are usually adopted by Secondary Users (SU) to fully utilize the wide range of spectrum. However, due to the constraints on transmission power, Secondary Users (SU) can only achieve short-range communication. If Primary Users (PU) transmits data all the time in a constant mode, spectrum underlay does not require Secondary Users (SU) to perform spectrum detection to find available spectrum band.

3.3.2 Spectrum Overlay

Spectrum Overlay is also referred to as opportunistic spectrum access. Unlike spectrum underlay, Secondary Users (SU) in spectrum overlay will only use the licensed spectrum when Primary Users (PU) are not transmitting, so there is no interference temperature limit imposed on Secondary Users (SU) transmission. Instead, Secondary Users (SU) need to sense the licensed frequency band and detect the spectrum white space, in order to avoid harmful interference to Primary Users (PU).

3.4 Spectrum Mobility

When a licensed (Primary) user is detected, the Cognitive Radio (CR) vacates the channel. This property of Cognitive Radio (CR) is described as the spectrum mobility

3.4.1 Spectrum Handoff

When the current channel conditions become worse or the Primary User (PU) appears and reclaims his assigned channel, Secondary Users (SU) need to stop transmitting data and find other available channels to resume their transmission. This kind of handoff in CR networks is termed as Spectrum Handoff [5]. Since the transmissions of Secondary Users (SU) are suspended during a spectrum handoff, they will experience longer packet delay. Therefore, a good spectrum handoff mechanism should provide with Secondary Users (SU) with smooth frequency shift with the least latency.

4. Spectrum Holes

Indeed, if we were to scan portions of the radio spectrum including the revenue-rich urban areas, we would find that

1) some frequency bands in the spectrum are largely unoccupied most of the time;
2) some other frequency bands are only partially occupied;
3) the remaining frequency bands are heavily used.

The underutilization of the electromagnetic spectrum leads to think in terms of spectrum holes, for which we offer the following definition:

A spectrum hole is a band of frequencies assigned to a primary user, but, at a particular time and specific geographic location, the band is not being utilized by that user.Spectrum Utilization can be improved significantly by making it possible for a secondary user (who is not being serviced) to access a spectrum hole unoccupied by the primary user at the right location.

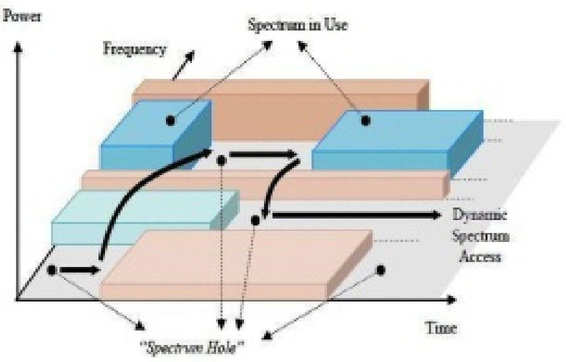

Figure 2 Illustration of Spectrum Hole Concept

Spectrum Sensing is defined as the task of finding spectrum holes or spectrum white space by sensing the radio spectrum in the local neighborhood of the Cognitive Radio (CR) receiver. The term, spectrum holes stands for those sub-bands of the radio spectrum that are underutilized at a particular instant of time and specific geographic location. The task of spectrum sensing involves the following subtasks: 1) detection of spectrum holes; 2) spectral resolution of each spectrum hole; 3) estimation of the spatial directions of incoming interferes; 4) signal classification.

5. Energy Detection

If CR can't have sufficient information about primary user's waveform, then the matched filter is not the optimal choice. However if it is aware of the power of the random Gaussian noise, then energy detector is optimal.

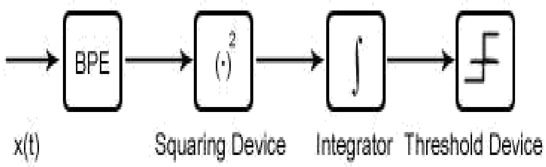

Figure 3 Block Diagram of Energy Detector

The energy detector as shown in figure 3 The input band pass filter selects the center frequency fs and bandwidth of interest W. The filter is followed by a squaring device to measure the received energy then the integrator determines the observation interval, T.

Finally the output of the integrator, Y is compared with a threshold, λ to decide whether primary user is present or not.

In a non fading environment where h is amplitude gain of the channel, probability of detection Pd and probability of false alarm Pf are given by following formulas [8]:

$$Pd=P(Y>\lambda/H_1)=Qm(\sqrt{2\gamma}\sqrt{\lambda})$$
$$Pf=P(Y>\lambda/H_0)=\Gamma(m,\lambda/2)/\Gamma(m)$$

where Y is the SNR, m = TW is the (observation/sensing) time bandwidth product Γ (.) and Γ (.,.) are complete and incomplete gamma functions, Qm ( ) is the generalized Marcum Q-function.

In a fading environment h is the amplitude gain of the channel that varies due to the shadowing or fading effect which makes the SNR variable. Pf is the same as that of non-fading case because Pf is independent of SNR. Pd gives the probability of detection conditioned on instantaneous SNR. In this case average probability of detection may be derived by averaging over fading statistics:

$$Pd=xQm(\sqrt{2\gamma},\sqrt{\lambda})f\gamma(x)$$

Where f γ (x) is the probability distribution function of SNR under fading.

A low value of Pd indicates an absence of primary user with high probability; it means that the CR user can use that spectrum. A high value of Pf indicates minimal use of spectrum.

We suggest that in fading environment, where different CR users need to cooperate in order to detect the presence of the primary user. In such a scenario, a comprehensive model relating different parameters such as detection probability, number and spatial distribution of spectrum sensors and more importantly propagation characteristics are yet to be found.

One of the main problems of energy detection is that performance is susceptible to uncertainty in noise power. It cannot differentiate between signal power and noise power rather it just tells us about absence or presence of the primary user.

5.1 Implementation of Energy Detection

The simplest detection technique for spectrum sensing is Energy Detection. As discussed about energy detector measures the energy received from primary user during the observation interval. If energy is less than certain threshold value then it declares it as spectrum hole. Let y is the received signal which we have to pass from energy detector. Flow chart of Energy Detection is shown in Figure 3. The procedure of the Energy Detector is as follows.

Step 1: First estimate Power Spectral Density (PSD) by using periodogram function in MATLAB.

Pxx = Periodogram(y)

Step 2: The power spectral density (PSD) is intended for continuous spectra. The integral of the PSD over a given frequency band computes the average power in the signal over that frequency band.

Hpsd= Dspdata.psd(Pxx)

Step 3: Now one frequency component takes almost 6 points in MATLAB. So for each frequency these points are summed to reach a result.

Step 4: On experimental basis when results at low and high SNR are compared then threshold is set to be 8000.

Step 5: Finally the output of the integrator, Y is compared with a threshold value to decide whether primary user is present or not.

6. SIMULATION RESULTS AND DISCUSSION

The cognitive radio system continuously searches the spectrum hole where primary user is not present and is determined by the method of energy detection. When it finds out the spectrum hole, immediately it allots to the Secondary User (SU) and whenever Primary User (PU) wants to occupy the slot, Secondary User immediately leaves it. The cognitive radio system using spectrum sensing cognitive radios find out the spectrum holes and secondary users are allowed to use that spectrum holes as long as it does not interfere the primary (licensed) users. Here we have used the digital implementation of energy detector using FFT. It is assumed that there are 5 primary users in the spectrum.

The carrier frequencies used for 5 signals are 1MHz, 2MHz, 3MHz, 4MHz, 5MHz and sampling frequency is 12MHz. Power spectrum density of signal is calculated and it is compared with the predefined threshold value to determine the presence of primary user signal. Here, we have assumed that 3rd , 4th and 5th primary users are present and 1st and 2nd primary users are not present as shown in figure 4. Primary User 1 and 2 are not present

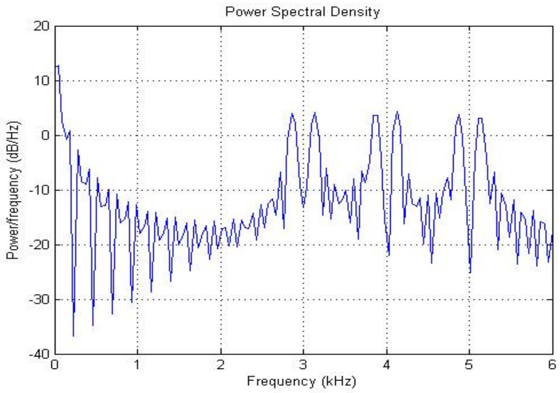

Figure 4 Primary User 1 and 2 are not Present.

The Cognitive Radio system will search the first available Spectrum hole of slot and automatically assign it to the secondary user as illustrated by Figure 5. Here the Secondary User is Allocated to the band of Primary User 1.

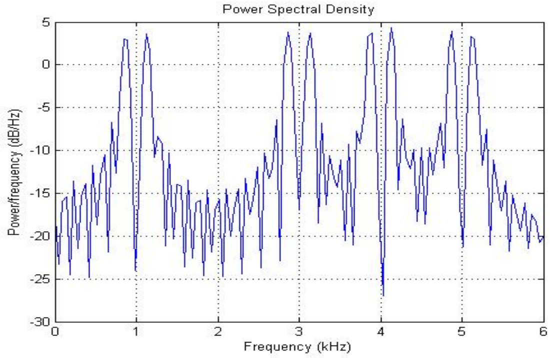

Figure 5 Secondary User- Allocated to Primary User 1

To analyze the channel characteristics we can add noise and attenuation parameter. Now if the Signal to Noise Ratio (SNR) is 17dB. Then, the following results are shown in the figure 6 and figure 7. The disturbance in the spectrum can be observed to decrease with the increase in SNR. This means that the noisy channel will increase the probability of error in the received signal. The PSD for attenuation signal is shown in figure 8.

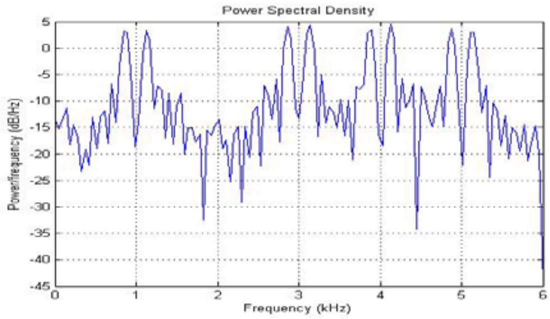

Figure 6 Adding Noise

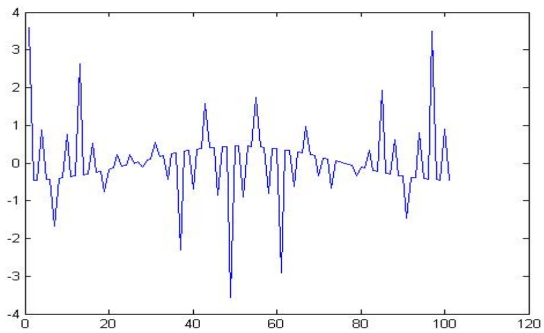

Figure 7 Adding Attenuation

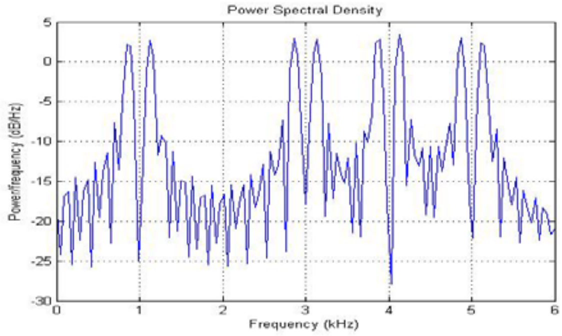

Figure 8 PSD for Attenuation Signal

Let us consider a scenario where we have assumed that all the primary users (1st, 2nd, 3rd, 4th and 5th primary users) are present and secondary user is not present as shown in figure 9.

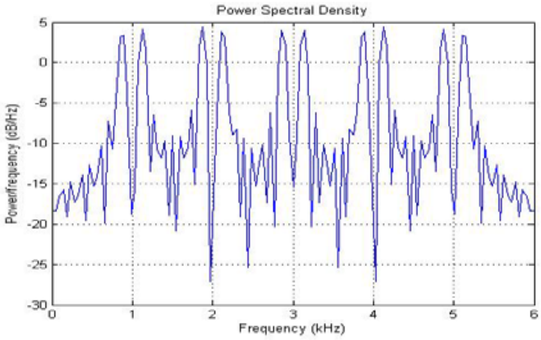

Figure 9 All the Primary User is Present

As all the Primary User were present there was no empty slot to assign the secondary user as shown in figure 10. So we want to empty a slot. Hence slot 3(Primary User) was fired as shown in figure 11 to accommodate the secondary user as inferred from figure 12,

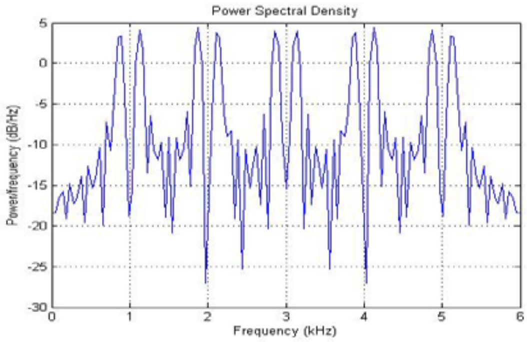

Figure 10 No way to assign Secondary User

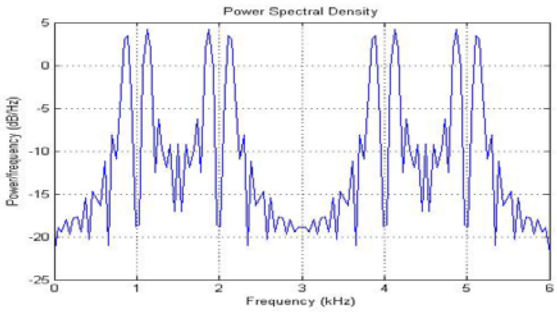

Figure 11 Primary User 3 was fired

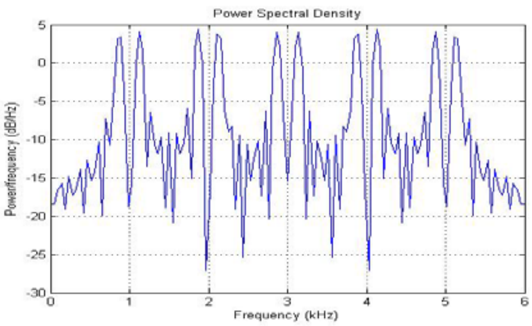

Figure 12 Secondary User is in slot 3 (PU)

PROBABILITY OF FALSE ALARM VS PROBABILITY OF MISS DETECTION

Detection of primary user by the secondary system is critical in a cognitive radio environment. However this is rendered difficult due to the challenges in accurate and reliable sensing of the wireless environment. Secondary users might experience losses due to multipath fading, shadowing, and building penetration which can result in an incorrect judgment of the wireless environment, which can in turn cause interference at the licensed primary user by the secondary transmission. The following plot (figure 13) represents the simulation and theory results for probability of detection and probability of false alarm. In cognitive radio networks, the criterion considered so far is in terms of protecting the primary user, i.e., maximizing the probability of detection under the constraint of probability of false alarm. In the simulation the probability of false detection is almost zero proving that the system is more effective.

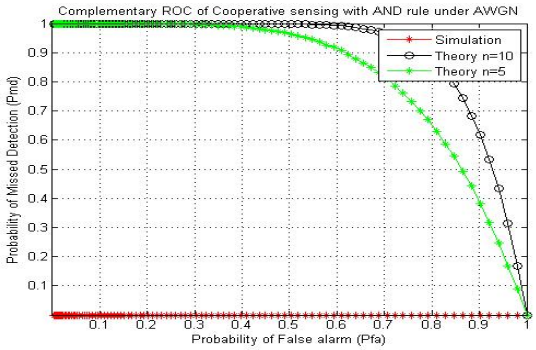

Figure 13 Probability of Missed Detection Vs False Alarm

7. Conclusion

This research was aimed towards the detection and classification of primary user's waveform in Cognitive Radio (CR) networks. The primary requirement of a spectrum sensing / detecting system is its real time processing and decision making. The proposed methodology has been implemented on a laptop and requires MATLAB support for simulation. Primary users are sensed with the help of energy detection mechanisms. In this paper main issues associated with spectrum sensing techniques are highlighted. The holes are identified and are assigned to the secondary users and the performance is studied by adding attenuation and noise too. The probability of missed detections and detections of false alarms is also studied. Performance of these spectrum sensing techniques limits due to uncertainty in the noise level. However the simulation results show an improved performance that are worth of the time spent on the research study and work.

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