SPECTRUM SENSING TECHNIQUES IN COGNITIVE RADIO

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***Abstract*— Wireless communications and the utilization of the radio frequency spectrum have been limited by Fixed Spectrum Assignment policy. According to Federal Communications Commission (FCC), temporal and geographical variations in the utilization of the assigned spectrum range from 15% to 85%. Cognitive Radio is a system that uses Dynamic Spectrum Access (DSA). Cognitive Radio must have ability to robustly sense the spectrum holes, if they want to use the spectrum opportunistically. This paper briefly discuss Transmitter Detection spectrum sensing techniques like Matched Filter Detection, Energy Detection and Cyclostationary Detection. A comparative analysis of above techniques is also presented.**

Keywords: Cognitive Radio, Spectrum Sensing, Spectrum Holes, Opportunistic Access,

INTRODUCTION

The limited available spectrum and the inefficiency in the spectrum usage necessitate use of existing wireless spectrum opportunistically [1]. Dynamic spectrum access is proposed to solve these current spectrum inefficiency problems. Dynamic Spectrum Access network exploits NeXt Generation (xG) netwoks that aim to implement the policy based intelligent radios known as cognitive radios. Cognitive radio techniques provide the capability to use or share the spectrum in an opportunistic manner. Dynamic spectrum access techniques allow the cognitive radio to operate in the best available channel. Cognitive radio enables the users to determine which portion of spectrum is available when it is not in use by licensed user. The main four operations of Cognitive Radio are: 1) Spectrum Sensing: Identifying the spectrum and detect the presence of licensed user (primary user) 2) Spectrum Management: Select the best available channel 3) Spectrum Sharing: Distribute spectrum fairly among xG users 4) Spectrum Mobility: Leave the spectrum on detecting a licensed user [1]. Among these operations, Spectrum Sensing is the most crucial operation to establish a Cognitive Radio. Sensing spectrum holes which are also referred to as White Space and vacant them as licensed user is detected requires binary decision for fast spectrum sensing.

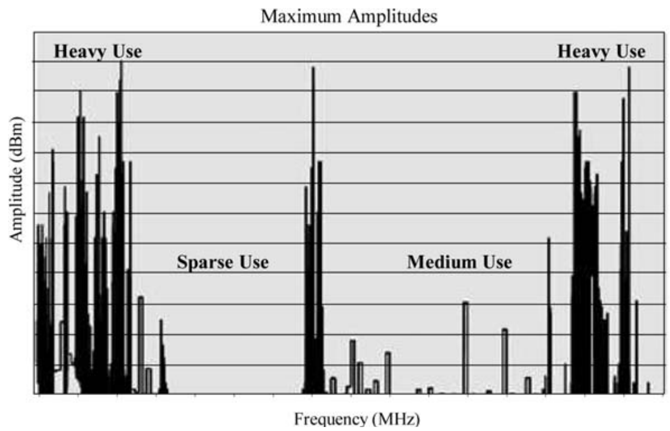

Figure 1: Spectrum usage [1]

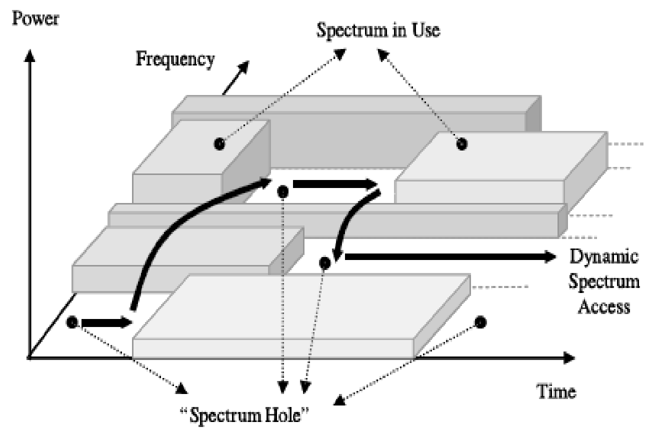

Figure 2: Spectrum white space [1]

Spectrum Sensing techniques discussed in this paper are Transmitter Detection techniques. The goal of spectrum sensing is to determine if a licensed band is not currently being used by its primary owner. This can be used to formulate binary Hypothesis testing problem as follows [2]:

$$x(t) = \begin{cases} n(t), & H_0 \ (\textit{white space}) \\ h\ s(t) + n(t), & H_1 \ (\textit{occupied}) \end{cases}$$

where x(t) is the signal received by the xG user, s(t) is the transmitted signal of the primary user, n(t) is the AWGN and h is the amplitude gain of the channel.

MATCHED FILTER DETECTION

Matched filter optimizes detection by maximizing received SNR. Given that it has a priori knowledge of the primary signal, coherency makes sure that only O(1/SNR) samples are needed for effective detection, thereby making detection faster so that an idle channel can be quickly occupied without delay. Matched filter is the optimum detector of a known signal in the presence of additive Gaussian noise. It is the linear filter that maximizes the SNR of the output. However, in order to use the matched filter within spectrum sensing, the xG user must be synchronized to the primary system and must even be able to demodulate the primary signal. Accordingly, the xG user has to have prior information about the primary system such as the preamble signaling for synchronization, pilot patterns for channel estimation, and even modulation orders of the transmitted signal etc.

Probability of false alarm for a given threshold is given as [3]:

$P_{fa,MFD} = Q(\frac{\gamma_{MFD}}{\sigma_n \sqrt{E}})$

Probability of detection is given as [3]:

$P_{d,MFD} = Q(\frac{\gamma_{MFD} - E}{\sigma_n \sqrt{E}})$

Where Q (.) is the Gaussian complementary distribution function.

In CR networks, the transmitted and its related characteristics are usually unknown or the availableknowledge is not precise. So the performances of matched filter degrade quickly which leads to an undesirable missed detection of primary users. It would require a dedicated sensing receiver for all primary user signal types. It requires large power consumption as various receiver algorithms need to be executed for detection.

ENERGY DETECTION

When xG user has no knowledge of primary user signal, energy detection is the most efficient technique of spectrum sensing. Due to its simplicity and no requirement on a priori knowledge of primary user signal, energy detection (ED) is the most popular spectrum sensing technique.

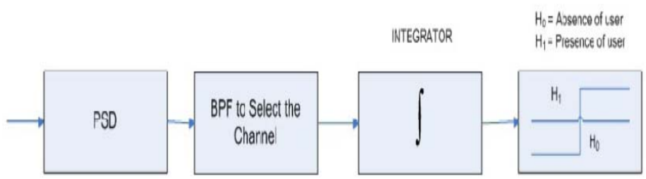

Figure 3: Block Diagram of Energy Detector [2]

Assume that the signal to be detected does not have any known structure that could be used for detection. Thus, we assume that the signal is also zero-mean circularly symmetric complex Gaussian. The log-likelihood ratio is [4]

$$\log\left(\frac{P(\mathbf{y}|H_1)}{P(\mathbf{y}|H_0)}\right) = \log\left(\frac{\frac{1}{\pi^N(\sigma^2+\gamma^2)^N}\exp(-\frac{\|\mathbf{y}\|^2}{\sigma^2+\gamma^2})}{\frac{1}{\pi^N\sigma^{2N}}\exp(-\frac{\|\mathbf{y}\|^2}{\sigma^2})}\right)$$

By removing all constants that are independent of the received vector **y**, we obtain the optimal Neyman-Pearson test

$$\Lambda_e \triangleq \|\mathbf{y}\|^2 = \sum_{i=0}^{N-1} |y_i|^2 \underset{H_0}{\overset{H_1}{\gtrless}} \eta_e.$$

If the energy detection can be applied in a non fading environment, the probability of detection Pd and false alarm Pf are given as follows:

$$P_d = P\{Y > \lambda|H_1\} = Q_m\left(\sqrt{2\gamma}, \sqrt{\lambda}\right),$$

$$P_f = P\{Y > \lambda|H_o\} = \frac{\Gamma(m, \lambda/2)}{\Gamma(m)},$$

Qm( ) is the generalized Marcum Q-function. From the above functions, while a low Pd would result in missing the presence of the primary user with high probability which in turn increases the interference to the primary user, a high Pf would result in low spectrum utilization since false alarms increase the number of missed opportunities. Since it is easy to implement, the recent work on detection of the primary user has generally adopted the energy detector.

Cognitive radios must be able to detect very weak primary user signals. However, there are some fundamental limits for detection in low SNR. For example, to set the decision threshold of the energy detector, the noise variance must be known. If the knowledge of the noise variance is imperfect, clearly the threshold will be erroneous. It is well known that the performance of the energy detector quickly deteriorates if the noise variance is imperfectly known. Due to uncertainties in the model assumptions, robust detection is impossible below a certain SNR level, known as the SNR wall. In a heavily shadowed or fading environment, spectrum sensing is hampered by the uncertainty resulting from channel randomness. In such cases, a low received energy may be due to a faded primary signal rather than a white space. As such, a secondary user has to be more conservative so as not to confuse a deep fade with a white space, thereby resulting in poor spectrum utilization. On the other hand, fading and shadowing effects may vary significantly depending on the receiver's location. Therefore, the uncertainty due to fading may be mitigated by allowing different users to share their sensing results and collaboratively decide on the occupancy status of the licensed band [25].

I. CYCLOSTATIONARY DETECTOR

An alternative detection method is the cyclostationary feature detection. A process x(t) is said to be second-order cyclostationary in the wide sense if its mean and autocorrelation function are periodic with some period $T > 0$

$$E[x(t)] = E[x(t+T)],$$
$$E[x(t)x(t+\tau)] = E[x(t+T)x(t+T+\tau)]$$

The cyclic auto-correlation function (CAF) is represented in terms of Fourier co-efficient as

$$R_x^{n/T_0}(\tau) = \frac{1}{T_0}\int_{-T_0/2}^{T_0/2} R_x(t,\tau)e^{-j2\pi(n/T_0)t}dt$$

'n/T0' represent the cyclic frequencies and can be written as 'α'. A wide sense stationary process is a special case of a wide sense cyclo-stationary process for '*n/T0*= α=0'.

The cyclic spectral density (CSD) representing the time averaged correlation between two spectral components of a process which are separated in frequencies by *'α'* is given as

$$S(f,\alpha) = \int_{\tau=-\infty}^{\infty} R_x^{\alpha}(\tau)e^{-j2\pi f\tau}d\tau$$

The power spectral density (PSD) is a special case of cyclic spectral density (CSD) for 'α=0'. It is equivalent to taking the Fourier transform of special case of wide sense cyclo-stationary for '*n/T0*= α=0'.

Modulated signals are in general coupled with sine wave carriers, pulse trains, repeating spreading, hopping sequences or cyclic prefixes, which result in built-in periodicity. These modulated signals are characterized as cyclostationarity since their mean and autocorrelation exhibit periodicity. These features are found by analyzing a spectral correlation function.

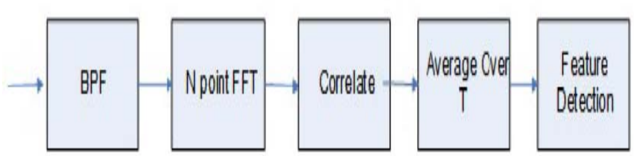

Figure 3: Block Diagram of Cyclostationary Detector [2]

The main advantage of the spectral correlation function is that it differentiates the noise energy from modulated signal energy, which is a result of the fact that the noise is a wide-sense stationary signal with no correlation, while modulated signals are cyclostationary with spectral correlation due to the embedded redundancy of signal periodicity. Therefore, a cyclostationary feature detector can perform better than the energy detector in discriminating against noise due to its robustness to the uncertainty in noise power.

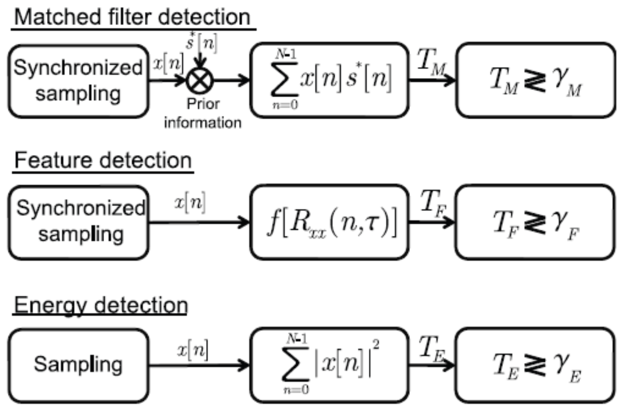

Figure 4: Operations of different detectors [4]

CONCLUSION

Transmitter Detection techniques for spectrum sensing are also known as Non-cooperative detection techniques. Matched Filter detection is complex to implement in Cognitive Radios as it requires a priori knowledge of primary signal but has highest accuracy. Also a cognitive radio using Matched detector would need a dedicated receiver for every type of primary user. Energy detector is least complex but least accurate compared to other approaches. As it is easy to implement, recent work on detection of primary user has generally adopted the energy detector. The performance of energy detector is susceptible to uncertainty in noise powem better than energy detector in discriminating against noise due to its robustness to the uncertainty in noise power. But it is computationally complex and requires long observation time. However, it performs better than energy detection in low SNR regions.

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