PSD based primary user detection in Cognitive Radio systems operating in impulsive noise environment

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Abstract - *Cognitive Radio presents a new opportunity area to explore for better utilization of a scarce natural resource like spectrum which is under focus due to increased presence of new communication devices, density of users and development of new data intensive applications. Cognitive Radio utilizes dynamic utilization of spectrum and is positioned as a promising solution to spectrum under-utilization problem. However, reliability of a CR system in a noisy environment remains a challenge area. Especially man-made impulsive noise makes spectrum sensing difficult. In this paper we have presented a simulation model to analyze the effect of impulsive noise in Cognitive Radio system. Primary user detection in presence of impulsive noise is investigated for different noise thresholds and other signal parameters of interest using the unconventional power spectral density based detection approach. Also, possible alternatives for accurate primary user detection which are of interest for future research in this area are discussed for practical implementation.*

Key Words: Cognitive Radio, Spectrum Sensing, Power Spectral Density, Impulsive noise, MATLAB Simulation

1.INTRODUCTION

Cognitive Radio is a much discussed solution area to utilize the scarce frequency spectrum in a more efficient way. Historically, Cognitive Radio was initially explored as an offshoot of Software Defined Radio (SDR) [1,2]. Cognitive Radio is a highly "*reconfigurable*" SDR which dynamically manages the radio communication parameters to efficiently and accurately provide communication opportunities to multiple users utilizing the same spectrum.

From the definition of CR [1], three primary CR tasks emerge:

1) Spectrum Sensing (*sensing radio communication environment)*
2) Identification of desirable communication channel
3) Dynamic spectrum management (*reconfiguring the radio to transmit and receive using the identified spectrum hole without disturbing the existing licensed users.)*

Several spectrum sensing techniques are being investigated to identify the presence of primary users. Traditional spectrum sensing techniques have been reviewed [5] earlier and various implementation approaches have been suggested [6], One of the challenges of all these spectrum sensing methods is to mitigate the problem of signal detection in noisy environment. As in any radio communication system, presence of noise in CR makes it difficult to spot the presence or absence of a primary licensed user at a particular time.

1.1 Noise in CR systems

Noise in CR systems is mostly assumed to be Gaussian in nature. This assumption works satisfactorily in low noise environment comprising predominantly of additive white Gaussian noise (AWGN) and operating under boundaries imposed by central limit theorem [8]. Various studies have been done to investigate performance of CR system in presence of Gaussian noise [9]. However, in practical scenario a CR system may have to operate in noise environments which may consist of impulsive noise or most likely a mixture of impulsive noise with AWGN [10-14].

Impulsive noise in communication systems is recognized as relatively short duration noise bursts of "on/off" nature. Examples of such noise includes electrical switching noise, atmospheric lightning or something as common as mouse clicks.

A digital impulse δ (t) , is defined as a signal which is true or 1 at a particular time instant and is false or zero at other times.

$$\delta(t) = \begin{cases} 1, t = 0 \\ 0, t \neq 0 \end{cases} \quad (1)$$

where *t* denotes a discrete time instance.

In practical CR systems, real impulsive noise may appear as a randomly arriving train of impulses of random duration and amplitudes. Typically, such an impulsive noise pulse may last up to 3 *ms* or even less. In case of audio signals such a noise is specially annoying.

A primary user is more difficult to detect in a CR system if the primary transmit power is low. Detection performance of a receiver is drastically degraded in presence of heavy impulsive noise environment. IEEE 802.22 standards expect detection of primary signals with power levels which are even -22 dB below the noise level [10]. We discussed Cognitive Radio and noise effects in Section 1. The rest of the paper is organized as follows: We present impulsive noise generation model we have adopted for this study in Section 3. Section 4 discusses effect of impulsive noise on PU detection in cognitive radio systems. Finally, Section 4 concludes the paper and outlines potential future research areas.

2. IMPULSIVE NOISE GENERATION MODEL AND MATLAB SIMULATION

To test the effect of impulsive noise in CR systems, a fairly accurate generation model for impulsive noise is needed. Two things need to be considered to generate impulsive noise: A train of impulses arriving at random interval with random amplitudes. Two main statistical models of impulsive noise available in theory are *Bernoulli–Gaussian* Model and *Poisson–Gaussian* Model [13]. However, studies have shown that arrival of short duration impulses is better modeled by *Poisson–Gaussian* Model. In our simulation model – developed in MATLAB - we have used the following impulsive noise generation model as shown in Fig.-1

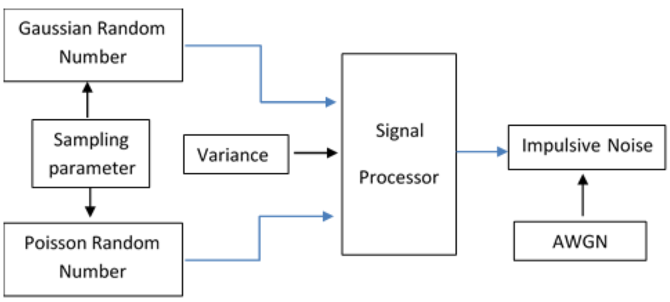

Fig-1: Impulsive Noise Generation Model

Sampling parameters like Number of Samples and scaling factor are entered as input. Signal variance levels for both AWGN and impulsive noise signal are also entered as input. Amplitude of impulsive noise is modeled as a random Gaussian distribution and arrival sequence is determined as per poisson distribution model. Since in real life situations, noise signal consists of White Gaussian Noise (AWGN) as always present, a small amount of AWGN is also added to impulsive noise to generate real life approximated noise signal for better noise performance evaluation. This AWGN is generated using a Gaussian distribution of mean = 0 and a user input variance.

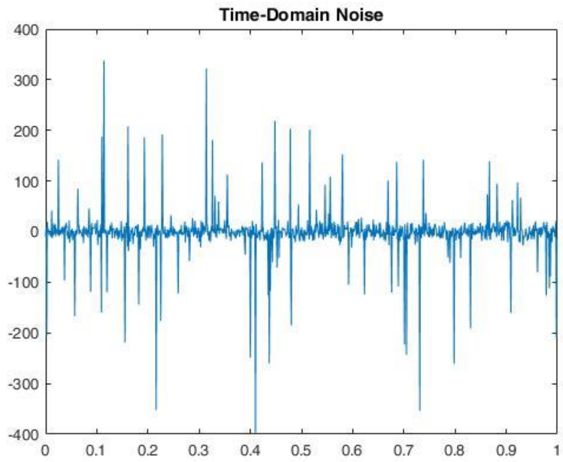

Fig -2: Simulated impulsive noise

A graphical interface i.e. GUI has been designed in MATLAB to simulate impulsive noise as shown in Fig-2. Such a tool helps to generate simulated impulsive noise for readily analyze the effect of random impulsive noise in channel.

3. SPECTRUM SENSING IN IMPULSIVE NOISE ENVIRONMENT

The objective of the spectrum sensing is to decide between the two hypotheses, namely [8,9].

$$x(t) = \begin{cases} n(t) H_0 \\ hs(t) + n(t) H_1 \end{cases} \quad (2)$$

where *x(t)* is the complex signal received by the cognitive radio, *s(t)* is the transmitted signal of the primary user, *n(t)* is the additive white Gaussian noise (AWGN) and *h* is the complex amplitude gain of the ideal channel or propagation channel coefficient. H_0 is the null hypothesis, which states that no licensed user is present in a certain spectrum band. H_1 *is* the alternative hypothesis which indicates that some primary user signal exists.

For the purpose of this paper, we have focused on non-cooperating spectrum sensing technique where the cognitive radio has to sense individually, the presence of primary users, estimate channel characteristics and make transmission decisions based on individual local observations [18-20]. For our simulation algorithm to detect presence of PU in impulsive noise environment we have used PSD based spectrum sensing approach. In conventional spectrum sensing techniques, energy detection has been a popular method for detection of PU in CR systems.
In energy detection technique, threshold λ is parameter of interest in detection of primary signal energy. Probability of

detection (P_d) and Probability of False Alarm (P_{fa}) both can be expressed as a function of threshold ʎ.

$$ʎ_{fa}= \sigma_n^2(1+(Q^{-1}(P_{fa})/ \sqrt{(M/2)}) \quad (3)$$

$$ʎ_d= \sigma_n^2 (1+SNR) (1+(Q^{-1}(P_d))/ \sqrt{(M/2)})) \quad (4)$$

There are certain advantages of using energy detection for spectrum sensing. For instance, it is a semi-blind detection method i.e. no a-priori information of transmitted signal is required. eliminate the need of information about transmitted signal, utilizing only noise power information to detect primary users. This makes the algorithm computationally less costly and also makes it easier to implement on hardware level [16].
However, there are certain limitations of energy detection technique like threshold determination (as depicted in equation (3), (4) above), poor detection performance in high noise environments. Also, energy detection does not work satisfactorily with wide spectrum signals.

For modulated signals, frequency domain methods can be explored because of the inherent periodicity. This periodicity lends itself to be exploited for detection of a carrier modulated signal in real life noisy environment.

3.2 PSD BASED SPECTRUM SENSING MODEL

Power Spectral Density (PSD) is defined as the frequency response of a signal of interest. PSD plot depicts the distribution of average power over a range of frequencies contained in the signal. The PSD of an analog signal x(t) can be expressed in two statistically equivalent methods:

1. Average of the square of FFT of signal

$$S_x(f) = \lim_{T\to\infty} E\left\{ \frac{1}{2T} \left| \int_{-T}^{T} x(t) e^{-j2\pi ft} dt \right|^2 \right\} \quad (5)$$

2. Using FFT of the signal's auto-correlation function.

$$S_x(f) = \int_{-T}^{T} R_x(\tau) e^{-j2\pi ft} dt \quad (6)$$

where $R_x(\tau)$ is the auto-correlation function

3. Power in *x(t)* in range *f1 - f2*:

$$P_{12} = \int_{f_1}^{f_2} S_x(f) df = R_x(0) \quad (7)$$

PSD has been explored earlier as an alternative means to sense spectrum holes in CR systems [15-17]. The uncertainty of a random valued entity can be forecasted by information theory. Shannon entropy method can be used to estimate the information encapsulated in a packet. It has been observed that in time domain, signal entropy gives a constant output for any value of SNR [5]. Hence, PSD as a frequency domain method gives a better chance of detecting the signal than time domain techniques like energy detection. Previous studies have been done in presence of AWGN noise. However, PSD detection needs to be tested in presence of impulsive noise environment which is closer to noise appearing in real life situations.

3.3 THRESHOLD DETERMINATION FOR PU DETECTION IN IMPULSIVE NOISE ENVIRONMENT

In our PSD based detector model as simulated in MATLAB, threshold power ʎ is parameter of interest in detection of primary signal power. In our analysis, a threshold is chosen based on the minimum statistics method [24]. This choice is directed by the observation that the received signal contains PU signal and noise which are mostly statistically independent of each other. This means that the resultant power of a noisy signal usually drops to the noise power level. Thus minimum of a noisy signal PSD will give us a fairly accurate threshold for our simulation for a range of signal to noise ratios (SNR).

$$ʎ = \min(\mathrm{psd}(s)) \quad (8)$$

where, ʎ is threshold power, ***s*** is received signal power.

3.4 SIMULATION MODEL AND RESULTS

Our Simulation model is a GUI based tool to analyze the efficacy and limitations of PSD based CR spectrum sensing techniques using a set of modulated received signal in a noisy channel. Noise in the channel is modeled to be impulsive noise. AWGN is also assumed to be present to approximate real life receiver environment.

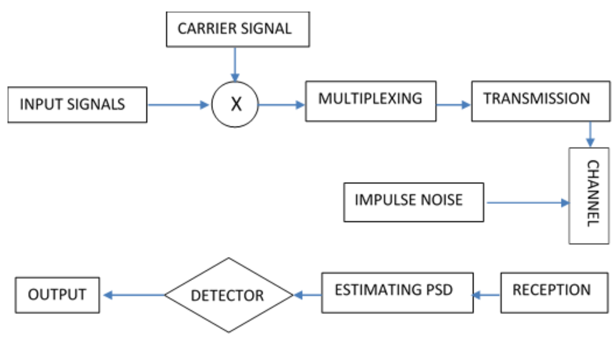

Fig-2 Block diagram of PSD detector used for sensing spectrum holes

A. *Signal characteristics in impulsive noise environment*

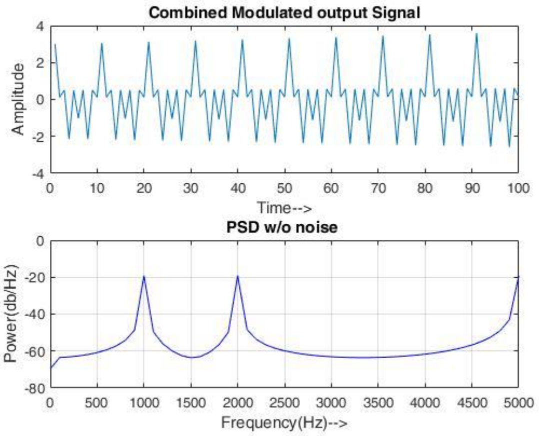

Fig-3 Periodogram of Received Signal

Our PSD based detector receives the simulated input signal which is mixed with impulsive noise. Periodogram of received signal is shown in Fig – 4.

B. *Probability of False Alarm vs Noise Threshold*

For a test case, a Constant False Alarm Rate (CFAR) system is employed. If the cognitive radio is required to guarantee a reuse probability of the unused spectrum, the probability of false alarm is fixed to a small value (e.g., 5%) and the detection probability should be maximized as much as possible. This is referred to as constant false alarm rate (CFAR) principle. In our simulations we have considered different scenarios to understand effect of impulsive noise on PSD spectrum sensing. The relationship between threshold λ and P_{fa} / P_d are given by 5 and 6 above.

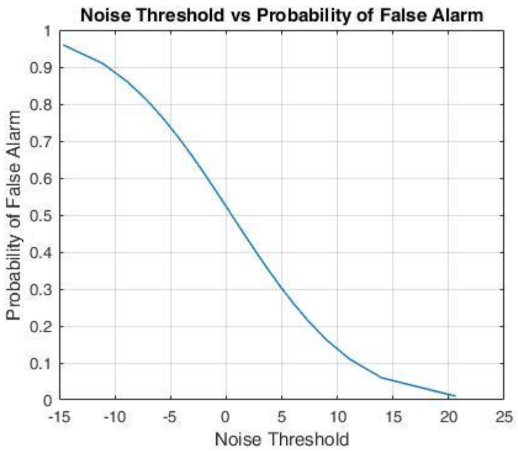

Fig-4 Variation of P_{fa} with respect to threshold for a fixed number of samples (M=300) and noise variance σ_n

comparison is estimated as a function of P_{fa} under fixed noise variance environment for a fixed number of samples. The result has been shown in Fig-4.

Then same simulation is repeated for varying number of samples M and results are shown in Fig-5. Number of samples M is varied in multiples of 100 i.e M=200, M=300 to M=1000. Noise variance (σ_n) is fixed at a value of 0.2 which is a typical value in CR systems.

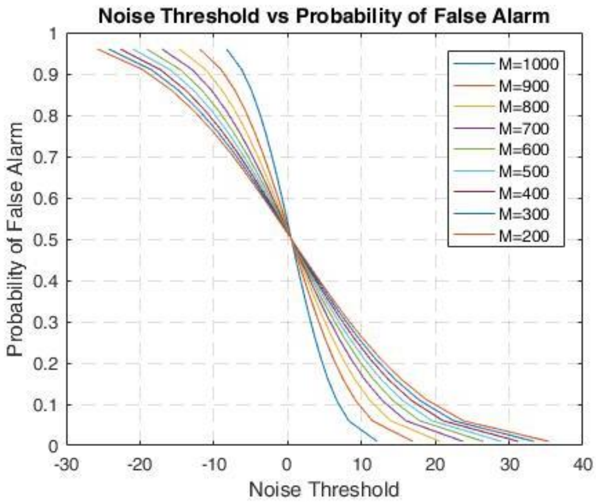

Fig-5 Variation of P_{fa} with respect to threshold for a varying number of samples (M) and fixed noise variance σ_n

The results clearly depict that as the number of samples is increased to a higher value, noise threshold for impulsive noise, gradually moves closer to the signal power indicating that threshold for detection decreases as received signal approximation at detector gets better.

This also shows that P_{fa} increases as impulsive noise signal merges with AWGN. The decrease in threshold in case of impulsive noise is sharper than in case of presence of only AWGN. Also it indicates that SNR wall [22] is lower in case of impulsive noise than that in case of AWGN only, though it makes signal recovery very difficult.

C. *Detection of PU using PSD based detector*

For the simulation analysis, different types of modulated signals are used as input to the MATLAB GUI window. Five different carrier frequencies are used rendering five different channels representing received signals in cognitive radio environment. These input signals are mixed with simulated impulsive noise (as discussed in section 2). Sinusoidal signal is used as a carrier signal. Input MATLAB window is as shown in Fig-6.

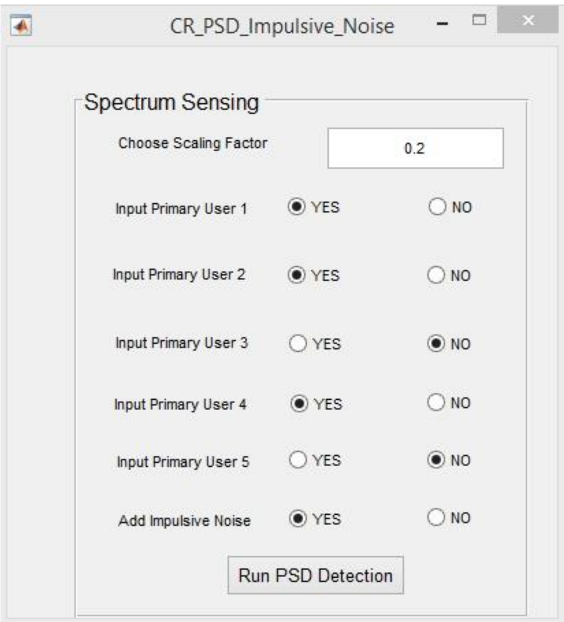

Fig-6 Window to select parameters to generate the impulsive noise sequence

At transmitter end, modulated input signals with different carrier frequencies are generated. These signals simulate five different channels representing five number of primary users (PUs). All signals are then multiplexed in MATLAB Simulink toolbox to get the final output signal. This final signal is mixed with simulated impulsive noise of desired amplitude and random impulse arrival distribution. At receiver end, PSD of the received multiplexed signal is estimated and its power content distribution in frequency domain is obtained. Presence or absence of PU is deduced on the basis of comparison of calculated PSD with threshold value. Estimated signal power is juxtaposed against the calculated threshold value as per (8). If the estimated power of received signal at the carrier frequency is higher than the threshold value, it is deduced that the primary user is present or it is deemed absent otherwise.

The presence or absence of a PU in a channel representing signal is indicated in the MATLAB output window (Fig-7)

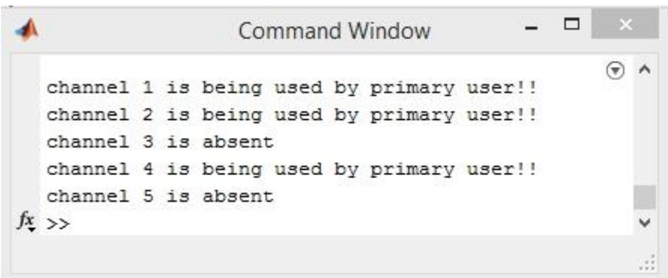

Fig-7 MATLAB Window showing PU detection results in a CR system with impulsive noise

The simulation experiment was repeated for varying SNR values and it was observed that detection performance is robust for typical impulsive noise signals but deteriorates as the noise signal strength increases.

4. CONCLUSION

It is established using simulation method that PSD based spectrum sensing can be used in impulsive noise environments. Though false alarm problem poses challenges at low SNR, the PSD detection is shown to work satisfactorily in typical impulsive noise environments. Also since it is simple to implement and less computationally intensive, it would be less costly than other non-cooperative spectrum sensing techniques like matched filter detection and cyclostationary detection methods. Clipping of impulsive noise signal and use of adaptive filters can improve detection capability at very low SNRs.

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