Cyclostationary feature detection based spectrum sensing in military radio receivers

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Abstract

Now a days scarcity of spectrum is a major issue in the field of wireless communication, so efficient usage of spectrum is needed. This can be achieved by using the cognitive radio. Major problem concerned with cognitive radio is spectrum sensing. A multi resolution fast filter bank using cyclostationary feature detection to sense the various ranges of spectrum in military radio receivers is proposed. It overcomes the constraint of fixed spectrum sensing. In cyclostationary feature detection small sub bands can also be sensed and the small sub bands can be used for LAN communications in military applications. By means of cyclostationary feature detection we can classify and identify the primary signal either Digital Video Broadcasting- Terrestrial (DVB-T) or wireless microphone signal. By using the knowledge of identifying primary signals will help cognitive radio to use fraction of TV band when only a wireless microphone signal is present in the channel. It can also detect some features of the primary signal like double sideband, data rates and the modulation type .

Index terms— cyclostationary feature detection, Digital vedio broadcasting – Terrestrial, LAN communication, multiresolution, microphone signal.

I. INTRODUCTION

THE demand for ubiquitous wireless services has been rised in the past and is expected to be the same in the near future. As a result, plenty of available spectral resources have already been licensed. So it appears that there is a little or no way to add any new lisenced users, unless some of the existing licensed users are discontinued. On the other hand, recent studies have stated that the vast portion of the licensed spectra are rarely used [3], [12]. This has initiated the idea of cognitive radio (CR), where secondary (i.e., unlicensed) users are allowed to transmit and receive data when primary (i.e., licensed) users are inactive. This is done in a way that the secondary users (SUs) are invisible to the primary users (PUs). Efficient utilization of frequency spectrum by cognitive radio (CR) systems has recently attracted much interest. An efficient and reliable spectrum sensing and detection scheme is a key feature that a CR air-interface must support. The efficiency of the scheme is critical because CR may have to scan a wide band of frequencies in a short period of time. Reliable sensing is equally important for keeping the interference to licensed (primary) users at a minimum level.

Traditionally, radio transmitters are constrained to operate within a band of frequencies that has been set aside for their sole use by regulatory bodies (so-called licensed bands). But with many legacy technologies present, and with many new wireless standards on the horizon, the 1-10GHz spectrum is quickly becoming saturated. Recent measurements, however, show that actual spectrum usage varies between 15% and 85% based on the location and time of day [6].

In the literature there are two main methods of spectrum, sensing they are energy detection and feature detection. Energy detection is implemented by averaging frequency slots by FFT. Feature detection, on the other hand, it dtects the exploited periodicity signal occurred during the modulations.

Rest of this paper is arranged as follows. Section II presents the wireless microphone sensing in that wireless microphone signal model, cognitive radio system description and state of art for the wireless microphone signal detection, cyclostationarity theory in section III, cyclostationary feature based MRSS algorithm in section IV, simulation results in section V and finally the conclusions in section VI.

II. WIRELESS MICROPHONE SENSING

A. The wireless microphone signal model

All the wireless microphones operate in the UHF band. Most of the wireless microphone uses an analog FM [6]. Let consider the signal has a spectral bandwidth B_X of 200 kHz. But, most of the concentrated signal energy is con in the bandwidth of 100 kHz. The transmitting power is in the range of few tens of mW. Therefore the coverage area is relatively low, obviously 500 meters for most of the powerful microphones.

The microphone signal, x(t), may be modeled as follows:

$$\boldsymbol{x(t) = A\,COS(2\pi f_o t + \frac{kf}{s_m}\int_t s(T)\,dT)} \quad \dots\ 1$$

where f_0 is the carrier frequency, k_f the frequency deviation of the FM , and s(t) is the modulating signal having an amplitude s_m. The signal x(t) has a power σ_x^2 equals to $A^\wedge 2/2$. Let y(t) be the microphone signal received by the opportunist receiver and n(t) is an Additive White Gaussian Noise (AWGN) with a zero mean and a variance σ_n^2.

$$y(t) = x(t) = n(t) \quad \dots\ 2$$

x(t) and n(t) being independent, but Signal to Noise Ratio (SNR) received by the opportunistic user is

$$\boldsymbol{SNR} = \frac{\sigma_x^2}{2\sigma_n^2} \quad \dots\ 3$$

B. The cognitive radio system description

The CR detector is having a condition is to detect the signals in the presence of noise. The problem can be described by the following hypothesis:

H0 : y(t) = n(t) ... 4

H1 : y(t) = x(t) + n(t) ... 5

where H0 - null hypothesis to denote that the event of "free band" and H1 is the alternative hypothesis for the event "occupied band".

By choosing one of the two assumptions H0 and H1, two kinds of errors can occur:

A FALSE ALARM ERROR:

In this case when the hypothesis H1 is chosen while the band is free. The false alarm probability is denoted by p_{FA},

A NON-DETECTION ERROR:

This error occurs when the hypothesis H0 is chosen while the band is occupied. The non-detection probability is denoted by p_{ND}.

The performance of the detectors is evaluated by computing the detection probability $p_D(p_D = 1 - p_{ND})$ for a given p_{FA}. The p_{FA} imposes the value of the absolute detection threshold. The probability, p_D, is given for different powers of the received signal in order to determine the minimum SNR which will be detected.

A challenge is to achieve high sensitivity at a low cost of complexity. The digital complexity is calculated in number of operations needed to provide a decision. This paper aims at proposing a detector with the best tradeoff in its detection sensitivity but not its complexity.

In our study, the detected band is a TV UHF channel, its bandwidth Bc is equal to 8 MHz in Europe and 6 MHz in the US.

C. State of the art of wireless microphone detection

wireless microphone sensing is not similar to the detection of digital TV signals which can use the characteristics of the Orthogonal Frequency Division Multiplexing modulation [2]. Wireless microphone sensing is difficult due to the presence of few characteristics of the signal.

Most of the literature references use a blind detection for the specific case of wireless microphones [5][10][9][8]. Energy and autocorrelation detections are detailed as comparison techniques for our study.

The energy detector computes a variable which is proportional to the energy of the received signal [11][4]. The test statistic T of this detector is given by:

$$T = \frac{1}{N_S} f(x) = \sum_{K=0}^{N_S-1} |Y[K]|^2 \quad \ldots\ 6$$

where Ns the number of samples of the analyzed signal. The autocorrelation based detection tests the stationarity of the signal by computing the samples autocorrelation function. First, the receiver estimates the autocorrelation function Cy[T] of the received signal:

$$C_y[T] = \sum_{K=0}^{N_S-1} y[K] y * [K-T] \quad \ldots\ 7$$

where * represents complex conjugation. then, the following test static is calculated[11];

$$T = \frac{\sum_{T=0}^{N_S-1} |C_Y[T]|^2}{|C_{y[0]}|^2} \quad \ldots\ 8$$

If there is no signal present, then the two terms should be roughly equal, since the non-central values (T ≠ 0) should be approximately zero. If the wireless microphone signal is present, the signal is not white and the statistical test should increase.

III. CYCLOSTATIONARITY THEORY

Data symbol is modeled as stationary random process; however communication signals are in general coupled with carriers, pulse trains, repeating sequences or cyclic prefixes due to this the periodicity of the signal becomes hidden. These communication signals have different features and are classified as cyclostationary random processes [13]. A signal *x (t)* is defined as second order wide sense cyclostationary if its statistics, mean and autocorrelation will be periodic with some period, *T*o:

$$\mu_x(t) = \mu_{x(t+T_0)} \quad \ldots\ 9$$

$$R_x(t,\tau) = R_x(t+T_{0,}\tau) \quad \ldots\ 10$$

If the autocorrelation function is periodic, then it can be represented by Fourier series [9]:

$$Ra_x(\tau) = lim_T \rightarrow (1/T \int_T x\,(t+\tau`/2) x(t-\tau/2) * e^{-j2\pi a t} dt \quad \ldots\ 11$$

$Ra_{x(\tau)\_}$ is called cyclic autocorrelation function (CAF) and it is used to examine the second order periodicity of the cyclostationary signals . if the signal is found to be cyclostationary with the period T then cyclic autocorrelation has a component at $\alpha = \frac{1}{T}$. cyclic autocorrelation is a time domain transform; its frequency domain equivalence can be found by establishing Weiner relationship.

$$s_x^a(f) = F\{Ra_x(\tau)\} \int_{-\infty} Ra_{x(\tau)e^{-j2\pi f t}} \, d\tau \quad \ldots\ 12$$

Where $Sa_x(f)$ is referred to as the spectral correlation function (SCF) or cyclic spectrum density(CSD). Obviously ,SCF is a 2-d symmetric transformation using two variables, they are the the cyclic frequency α and the spectral frequency f. power spectral density (PSD) is a special case of SCF when α = 0. $PSD = S^a x(f)$.

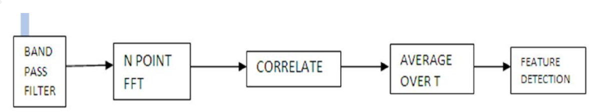

Figure1 Block diagram of cyclostationary feature detection

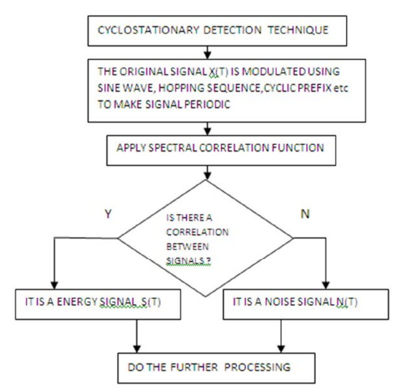

Figure2 Flow diagram of cyclostationary feature detection

This detector exploits the periodicity in the received primary signal to identify the presence of primary users (PU). The periodicity is commonly embedded in cyclic prefixes or hopping sequences, pulse trains, sinusoidal carriers, spreading codes of the primary signals. Due to this periodicity, the cyclostationary signals exhibit the features of periodic statistics and spectral correlation, which is not present in stationary noise and interference [7].

Thus, the cyclostationary feature detection is robust to noise uncertainties and performs better than energy detection in low SNR regions. Eventhough it requires a priori knowledge of the signal characteristics, cyclostationary feature detection is having ability to differentiate the CR transmissions from various types of PU signals. Here there is no need of synchronisation as of energy detection in cooperative sensing. However , CR users need not to keep silence during cooperative sensing so it improves the overall CR throughput.

IV. CYCLOSTATIONARY FEATURE BASED MRSS ALGORITHM

Since the spectrum sensing is the most basic thing for CR to detect unused spectrum and share it without harmful interference, here we proposed the cyclostationary feature based MRSS architecture . As a fast coarse /wideband sensing, DWPT energy detector is first performed by searching the whole scanning frequency. It selects the unoccupied channels by sorting the channels into large, small and negligible sub-bands energies. Most probably the negligible sub-band energy is having high probability to be unoccupied and the channel with large sub-band energy to be occupied by a wideband signal. So the channel with small sub-band energy is examined by the cyclostationary feature sensing for identifying the channel status. Then, fine/feature sensing is performed for channel with a signal . Finally by using the outputs of the proposed scheme, unoccupied channels will be detected and it will be set for unlicensed or CR users.

V. SIMULATION RESULTS

Primary signals with different center frequencies and SNR are considered. The center frequencies of nine primary user's signals and their SNRs are fixed as f=12, 44, 52, 60, 76, 84, 92, 108, 116 MHz and SNRs=20, 7, 8, 10, 9, 12, 13, 11, 9 dB. Figure 3 shows the received signal at the CPE using the FTT scheme. Since center frequencies are 12, 52, 60, 76, 84, 92, 108, 116, we anticipate the energy of channel 2, 6,7,8,10,11,12,14 and 15 are larger than the other channels. Fig.4 shows this result and 16 channels are sorted like Figure 5.

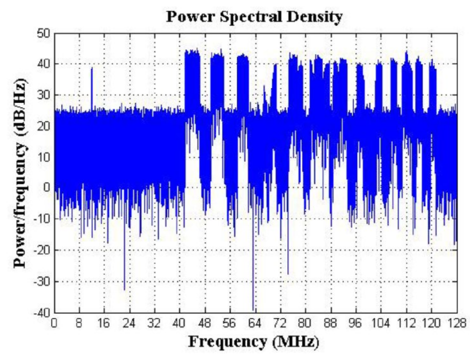

Figure 3 Received signal at CPE

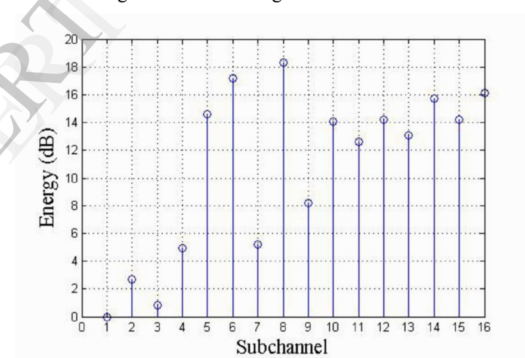

Figure 4. Energy of channel

1	3	2	4	7	9	11	13
10	12	15	5	14	16	6	8

Figure 5. Sorted channel at level 4 DWPT

The output sorted channels are classified into large, small and negligible sub band energy like Figure 6 and Figure 7.

1	3	2	4	7	9

Figure 6. Small and negligible sub band energy

11	13	10	12	15	5	14	16	6	8

Figure 7 Large sub band energy

We anticipate that the large sub band energy has a high probability to be occupied by the TV signal whose bandwidth is 8 MHz which is the frequency range of each sub band. In this condition fine resolution sensing is not needed and the cognitive radio will either start communicates or wait for a licensed user to free the spectrum.

We anticipate that the negligible sub band energy has a high probability to be unoccupied. The spectral correlation function of channels indexes of small sub band energy is computed. Figure 8 shows the surface plot of the SCD estimate magnitude of wireless microphone signal disturbed by WGN noise. The sub band contains the primary user signal which is the wireless microphone with a 200 kHz bandwidth compared to sub band frequency range is very narrow bandwidth. In this condition fine resolution is needed. The sub band with wireless microphone signal features is decomposed using a five-level DWPT. Figure 9 shows this result and 32 channels are sorted as shown in Figure 10.

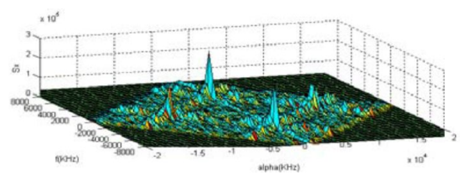

Figure 8 Surface plot of the SCD estimate for wireless microphone signal (channel 2, level 4-DWPT)

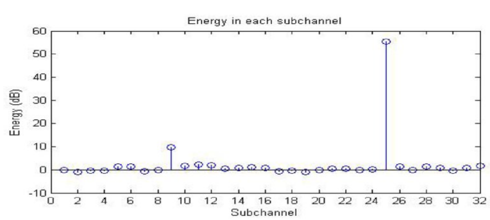

Figure 9 .Energy of channel (level 9-DWPT)

23	17	2	4	30	19	18	28
24	8	7	20	1	6	27	22
32	29	21	3	31	11	5	12
26	13	14	15	10	16	9	25

Figure 10 Sorted channel at level 9 –DWPT

The output sorted channels is classified into a small and negligible sub band energy. The negligible sub band energy has a high probability to be unoccupied. We focus on the SCF features of the channel with small sub band energy. A sinusoidal signal at a frequency of *fc* is found to have four peaks in SCF as shown in Figure 11. This means the wireless microphone exist under the sensing bandwidth which is 0 - 250 KHz. In this case we repeat sensing the same bandwidth for certain period of time.

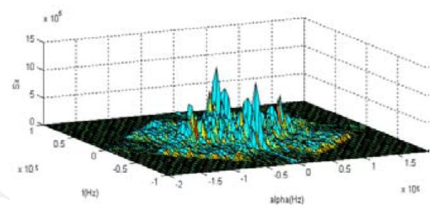

Figure 11 Surface plot of the SCD estimate for wireless microphone signal, channel 25.

VI. CONCLUSION

Since the spectrum sensing is the basic requirement for cognitive radio to detect a spectral hole, we proposed a MRSS using cyclostationary feature detector method to classify and identify the primary users and to locate the hole. The performance of the proposed scheme has been evaluated under noise uncertainties of 0, 1, 2, and 3 dB. The evaluation results clearly indicate that the performance can be achieved by the application of the proposed scheme especially in a low SNR environment. In conclusion, this paper has demonstrated that by combining the simplicity of the energy detector and therobustness of a cyclostationary feature can offer improvements in the radio spectrum utilization for cognitive radio.

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