A Spectrum Sensing Method Using Output of PFD

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Abstract— Spectrum sensing is an important function of Cognitive Radio. In this paper, a spectrum sensing method is proposed based on the output of a PFD. It is a blind spectrum sensing method that doesn’t require knowledge of incoming signal. The probability of false alarm and probability of detection are calculated for AWGN and sine wave input. The PFD gives fast and accurate results. This method has lower complexity and is better than other single antenna sensing methods.

Index Terms— Cognitive Radio (CR), frequency comparison, PFD, spectrum sensing.

I. INTRODUCTION

The main aim of CR is to explore the unused frequency spectrum and allocate it to the users who are in need of it. Basically there are two types of users: Primary users are the ones who own a particular band of frequencies and the secondary users who want to make use of vacant frequency bands owned by primary users. The function of CR is to allocate efficiently this vacant band to SU without harming the function of PU. There are two types of spectrum sensing methods: blind spectrum sensing in which the CR need not have any knowledge about the PU and feature based sensing in which CR should be aware of various parameters like type of modulation, sampling rate, etc. Various methods are used for spectrum sensing. Energy detection is the most easy and likely to be used method. In this method the output of an energy detector is compared with a threshold and depending on the output, the presence or absence of the signal is given. There are various multiple antenna methods like the one given in [3]. This method requires the channel state information as prior knowledge. Based on statistical properties of F-distribution, the test threshold and Pd are derived. Koufos et.al have proposed a distributed sensing in multiband CN for optimal sensing of multiple spectrum bands by multiple cognitive users.

In this paper, a new blind spectrum sensing method is proposed. In this method, there is a frequency comparison using a PFD. A comparison is made between a reference frequency and an input and output of PFD is accumulated for a specific window time. Depending on this a decision is made on the existence of the signal. The difference between a noise and signal plus noise is considered in zero crossing numbers. As PFD is a state machine, the expression of its output couldn’t be described by mathematical formulas.

Thus only the analytical derivation for AWGN model with sine wave input is evaluated.

The remainder of this brief is organised as follows. In section II, a brief description of the PFD is given. Section III describes the proposed sensing method. Stastical analysis is given in section IV. Section V gives the simulation and results. Section VI concludes the paper.

II. PFD

PFD is a circuit that detects phase and frequency differences between two input signals, A and B. It has two uncomplimentary outputs QA and QB. The reference input A has a frequency fA. Another input B has frequency fB. Three situations arise, if fA<fB, then the output QB has pulse response with unequal widths and the other output has impulses with a repetition period equal to the period of input B. If fB<fA, the output QA has pulse response and QB has impulses with repetition period equal to the period of input B. In equal frequency situation, PFD acts as a phase comparator and one output has a pulse response with equal widths, apparent in Qi where i is the leading input.

III. PROPOSED SENSING

The received signal is first bandpass filtered and amplified in LNA. It is further mixed with the LO signal and filtered again in second BPF in the range [fa,fb]. It is limited in a limiter and given as an input to PFD. Second input to PFD is the reference clock. Input B is the unknown signal with the carrier frequency fB and phase ΨB. If fA<fB then output QB has pulse pattern with unequal widths and QA has impulses with period of A. If fA>fB, the output behaves in opposite manner. In the equal frequency situation, PFD acts as a phase comparator. The output of a PFD is accumulated in an accumulator for a specific time interval to generate a pair of SA,SB which are used for decision making. SA and SB are then reset and ready for next monitoring interval.
The blind sensing algorithm is as shown. The lower edge of frequency band is \( f_a \). The downconverted bandlimited input is first compared with \( f_a \) i.e. \( f_A = f_a \). If \( S_A \leq N - N_d \), the output shows situation of impulse pattern for QA and pulse for QB implying \( f_A < f_B \). The input is then compared with upper edge frequency \( f_b \) i.e. \( f_A = f_b \). If \( S_B \leq N - N_d \), the output shows the situation of pulse pattern for QA and impulse for QB. Hence \( f_A > f_B \). The comparison with \( f_A = f_B \) repeats \( n_r \) times and if \( S_B \) remains constant in all \( n_r \) comparisons, it confirms the existence of the signal.

![Fig. 2 Proposed Algorithm.](image)

### IV. STATISTICAL ANALYSIS

The probability of detection and FA are calculated for sine wave input. Two hypothesis are considered. H0, when the channel is vacant and H1, when the channel is occupied.

#### A. Detection Probability

In the proposed system, the detection occurs when \( s_A \leq N - N_d \) for \( f_A = f_a \), \( s_B \leq N - N_d \) for \( f_A = f_b \) and \( S_B \) remains constant in all \( n_r \) repetitions of \( f_A = f_b \). The detection probability can be written as

\[
P_B = P_r( ((s_A \leq N - N_d) f_A = f_a) \& (s_B \leq N - N_d) f_A = f_b) \\
\quad \& (\forall i \in U : s_B^i = s_B^{i+1} f_A = f_b) (H_1) \\
= P_r(s_A \leq N - N_d) f_A = f_a H_1) \\
\cdot ( \sum_{k=0}^{N - N_d} (P_r(s_B^k \neq k f_A = f_b, H_1))^{n_r} )
\]

Where \( U = \{2, 3, \ldots, n_r\} \). We consider the time of the \( i \)th UZC of A with \( t_A^i (i = 0, 1, 2, \ldots) \) and the number of input B UZC in the time interval of \( [t_A^i, t_A^{i+1}] \) by \( n_r \). At first the output QA goes up to generate the pulse output. Whenever \( n_r < 2 \), the output remains as before, but when \( n_r \geq 2 \), the output changes.

To see the result of \( s_A \leq N - N_d \), QA should change from its first pulse output to impulse output and keep this result in all \( N - N_d \) last cycles of monitoring time. Thus

\[
P_1 \triangleq \sum_{i=1}^{N_d} (P(n_i \geq 2), \prod_{j=i+1}^{N} P(n_j) \geq 1) (\prod_{k=1}^{N - N_d} P(n_k < 2))
\]

To see the result of \( s_B \leq N - N_d \), QA can keep its first pulse output or change from its first output and go back to it again somewhere in the first \( N_d \) cycles. In \( N - N_d \) effective cycles, the QA and QB should keep the result of pulse and impulse, respectively. Thus

\[
P_2 \triangleq \sum_{i=1}^{N_d} P(n_i < 2) + \sum_{i=1}^{N_d} (P(n_i \geq 2) \\
\cdot \sum_{j=i+1}^{N_d} (P(n_j = 0), \prod_{k=j+1}^{N} (P(n_k < 2))))
\]

Now, we define \( P_n(t, a_f, b_f, \varphi_B) \) as probability density function (PDF) of a noisy sine wave. We can write

\[
P_{m}(0, a_f, b_f, \varphi_B, t_1, t_2) = \left( 1 - \int_{t_1}^{t_2} P_u(t, a_f, b_f, \varphi_B) \, dt \right) u(T_{end} - (t_2 - t_1))
\]
\[ P_{nu}(1, a, f_B, \Phi_B, t_1, t_2) \times \]
\[ = (t_{z1}^{+}) P_u(t, a, f_B, \Phi_B) \]
\[ (P_L + (1 - P_L) \int_{t_1}^{\infty} P_t(\tau, a, f_B) \, d\tau) \times \]
\[ \cdot (t_{z1}^{+}, f_0(t, a, f_B) \, d\tau) \times u(2T_{end} - (t_2 - t_1)) \]  

(5)

In which \( u(x) \) is the step function, \( P_L = P_{nu}(0, a, f_B, \Phi_B, t) \) and \( P_t(\tau, a, f_B) \) is the PDF of time interval between successive UZCs of a noisy sine with frequency \( f_B \).

\[ P(n_k < 2) = P_{nu}(0, a, f_B, \Phi_B, t_k^{1}, t_k^{2}) + P_{nu}(1, a, f_B, \Phi_B, t_k^{1}, t_k^{2}) \]  

(6)

\[ P(n_k \geq 2) = 1 - P(n_k < 2) \]  

(7)

\[ P(n_k \geq 1) = 1 - P_{nu}(0, a, f_B, \Phi_B, t_1, t_2) \]  

(8)

B. FA Error

When the channel is vacant and the outputs show an occupied one, the FA error occurs. The needed conditions for FA error is similar to detection conditions and it can be given by

\[ P_{FA}(\tau) = P_{nu}(0, a, f_B, \Phi_B, t) \]

\[ \times (1 - P_L) \int_{t_1}^{\infty} P_t(\tau, a, f_B) \, d\tau \times u(2T_{end} - (t_2 - t_1)) \]  

(9)

\[ P(s_k < N - N_d | f_A) = \sum_{n_k=1}^{N_d} P(n_1 \geq 2) \times (\prod_{i=1}^{n_k} P(n_i \geq 1)) \times (\prod_{i=1}^{N_d} P(n_k < 2)) \]  

(10)

\[ P(s_k \leq N - N_d | f_A) = \prod_{i=1}^{N_d} P(n_i < 2) \times \sum_{n_k=1}^{N_d} P(n_k < 2) \]  

(11)

Considering that \( P^n_P(t) \), as the PDF of input noise, has upward zero crossing at time \( t \), we have

\[ P_{nu}(0, t_1, t_2) = (1 - (t_{z1}^{+}) P_u(t, a, f_B) \, d\tau) \times u(\frac{N_0}{2} - (t_2 - t_1)) \]  

(12)

\[ P_{nu}(1, t_1, t_2) = \frac{N_0}{2} \int_{t_1}^{t_2} (P_L^n + (1 - P_L^n) \int_{t_1}^{\infty} P_t^n(\tau) \, d\tau) \times \]

\[ \cdot \int_{t_2-\tau}^{t_2} u(\frac{N_0}{2} - (t_2 - t_1)) \]  

(13)

Because of the discrete values of \( N \) and \( N_d \), FA error could not be an arbitrary value, and only some discrete values can be achieved. It can simply be shown that the needed time for detection in each band of \([f_a, f_b]\) is

\[ T = (\frac{1}{f_a} + \frac{n_d}{f_b}) \]  

(14)

V. SIMULATIONS AND RESULTS

In this section, the results obtained till now are presented. Fig 3 shows a message signal. Fig 4 shows a bandpass filtered signal. Fig 5 shows an oscillated signal. Fig 6 shows the mixer output. Fig 7 shows the bandpass filtered signal. Fig 8 shows second input signal. Fig 9 shows the PFD output.
VI. CONCLUSION

A new spectrum sensing method based on PFD output is proposed. It is a blind spectrum sensing method. It needs no knowledge about the input signal or the noise variance and is applicable in practical CR applications. This method outperforms the previous single antenna methods.

REFERENCES