Scattered Pilot Detection of CMMB Signals based on Data Smoothing in Cognitive Radio Networks

Huiheng Liu, Zhengqiang Wang, Weijin Jiang

Abstract**—**This paper investigates the cyclostationarity of China multimedia mobile broadcasting (CMMB) signals. A scattered pilot detection algorithm with lower complexity of CMMB signals based on data smoothing for cognitive radio networks is proposed. First, the received data in secondary user is smoothed by the first order lag filter. Then the cyclic autocorrelation functions (CAFs) of the odd and even orthogonal frequency division multiplexing (OFDM) symbols in CMMB signals, as the decision statistics are calculated. According to the signature of CMMB signals, appearing some peaks of scattered pilots for the cycle frequency $\alpha = 0$ around the delay lags $\tau = n{T_u}/{4}$, $n = 1,2,3$, as dominant peaks of CAF is used to detect the CMMB primary user. We derive and simplify expressions of these two decision statistics, and we use the OR rule to decide whether the CMMB primary user is present or not. Simulation results show that by using longer sensing time, the detection performance of the proposed algorithm is significantly improved.

Keywords**—**scattered pilot detection, cyclic autocorrelation function (CAF), data smoothing, CMMB, cognitive radio networks.

I. INTRODUCTION

RADIO spectrum, an expensive and limited resource, is surprisingly underutilized by licensed users. Such spectral underutilization has motivated cognitive radio (CR) technology, which enables secondary users (SUs) to opportunistically access spectrum holes [1]. As a fundamental and key issue in cognitive radio networks (CRNs), spectrum sensing has been explored comprehensively [2]-[3]. There are basically two spectrum sensing methods, narrowband sensing and wideband sensing. In practice, due to either high implementation complexity or high financial/energy costs, wideband sensing schemes are difficult to design [4]. Among narrowband sensing techniques, such as the energy detection (ED), matched filter detection (MFD) and cyclostationary feature detection (CFD) are the most popular methods addressed in the literature [5]-[6]. MFD needs perfect knowledge of the primary user (PU) signal and channel propagation which aren't known for SUs. ED doesn't need any prior information on the PU signal. It is robust to unknown fading channels. However, ED must know the background noise, and it is very susceptible to the noise uncertainty. CFD can well distinguish between the signal and noises, and it is robust to the noise uncertainty. Though computational complexity, CFD is frequently used for spectrum sensing, especially for some signals with cyclostationary signature, i.e. orthogonal frequency division multiplexing (OFDM). OFDM is the most popular modulation scheme in communication and broadcasting systems, such as digital video broadcasting - terrestrial (DVB-T), worldwide interoperability for microwave access (WiMax), long term evolution (LTE) and China multimedia mobile broadcasting (CMMB) [7]. CMMB is a mobile television and multimedia standard developed and specified in China. It provides broadcasting and television services for mobile phones, iPads, and other small screen portable terminals using S-band satellites.

Most of the existing OFDM spectrum sensing methods make use of the cyclic prefix (CP) or cyclostationarity of OFDM signals [8]. Spectrum sensing for the signal with the cyclostationarity is usually realized by calculating its cyclic autocorrelation function (CAF). Its second-order cyclic cumulants form with multiple cycle frequencies has been addressed in [9]. Furthermore, in order to reduce the amount of transmitted data, a censoring cooperative detection scheme also was proposed in [9], which can achieve almost the same detection performance when compared with the cooperative scheme. The hard and soft decision combining cooperative detection schemes of the CFD method were analyzed in [10]. Unfortunately, despite its high sensitivity, these detectors suffered from high complexity. However, for some OFDM signals embedded with pilot signals, i.e. CMMB, it is possible to reduce the complexity of this method by calculating the CAF with some special delay lags. We consequently propose a scattered pilot detection algorithm based on data smoothing for CMMB signals. According to the position of scattered pilots,

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some special delay lags, $\tau = n\, T_u/4$ around where n=1, 2, 3, T_u is the used time of an OFDM symbol of CMMB signals, are selected to compute the decision static, CAF, with the cycle frequency $\alpha = 0$. The proposed algorithm has a lower complexity than the detection methods of the second-order or higher orders cyclic cumulants form.

II. Signal Feature of CMMB Signals

In CMMB systems, the channel's bandwidth can be either 2 or 8 MHz, depending on the data rate. One frame of CMMB consists of 40 time slots and the length is 25ms. Each time slot consists of one beacon signal and 53 OFDM symbols. The OFDM symbol of CMMB is modulated with BPSK, QPSK, QAM16, or QAM64, in which the length of cyclic prefix is 1/8 time of the data length.

In modern communication systems with OFDM modulation, pilots are regularly repeated in blocks of subcarriers to estimate the channel in all subbands. This regular existence of pilots will result in the emergence of some cyclostationary features. In CMMB systems, pilot signals are intelligently designed to satisfy the channel estimation requirement, which should guarantee the high probability of correct demodulation. As depicted in Fig. 1, three types of effective subcarriers, data, scattered pilot, and continual pilot, are usually set up, where is the number of effective subcarriers. For B=2MHz mode, the amount of data, scattered pilots, and continual pilots are 522, 78, and 28, respectively.

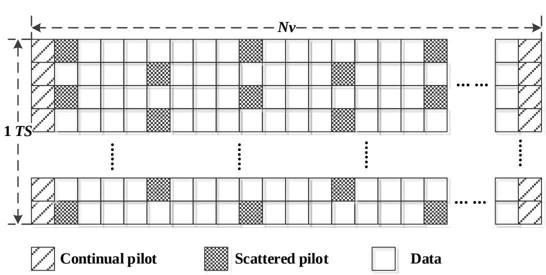

Fig. 1. The subcarrier positions of continual pilots, scattered pilots and data of CMMB signals in one time slot (1TS)

In the arrangement of circular configuration, the position of the scattered pilot subcarrier indexes in CMMB systems periodically changes, and it repeats every 8 subcarriers. Furthermore, scattered pilots have more numbers in comparison with continual pilots. Therefore, scattered pilots of CMMB systems will generate a well-detectable signature.

If the channel bandwidth is 2MHz, the position of the *m*th scattered pilot in the *n*th OFDM symbol is as follows:

$$\begin{aligned}
&\text{if } \ mod(n,2) == 0 \\
&\quad m = \begin{cases} 8p+1, & p = 0,1,\cdots,38 \\ 8p+3, & p = 39,40,\cdots,77 \end{cases} \\
&\text{if } \ mod(n,2) == 1 \\
&\quad m = \begin{cases} 8p+5, & p = 0,1,\cdots,38 \\ 8p+7, & p = 39,40,\cdots,77 \end{cases}
\end{aligned} \tag{1}$$

III. Theoretical Analysis of Scattered Pilot Detection of CMMB Signals based on Data Smoothing

A. Cyclostationarity

The process $x(t)$ is assumed to be a second-order cyclostationary if its mean and autocorrelation function are periodic with period T_0 . It can be written as

$$R_{xx}(t,\tau) = R_{xx}(t+T_0,\tau) = E\left[x(t+\frac{\tau}{2})\, x^*(t-\frac{\tau}{2}) \right] \tag{2}$$

Because of the periodicity of the autocorrelation function, it can be represented by its Fourier series expansion

$$R_{xx}(t,\tau) = \sum_{\alpha} R_{xx}^{\alpha}(\tau) e^{j2\pi\alpha t} \tag{3}$$

where

$$R_{xx}^{\alpha}(\tau) = \lim_{T_0\to\infty} \frac{1}{T_0} \int_{-\frac{T_0}{2}}^{\frac{T_0}{2}} R_{xx}(t,\tau) e^{-j2\pi\alpha t} dt \tag{4}$$

is CAF of $x(t)$, α is called the cycle frequency, where $\alpha = m\frac{1}{T_0}$, and m is an integer.

B. System Model

The scattered pilots of CMMB signals are repeated every 8 subcarriers, specified with special values, 1+0*j*. When the PU of CMMB is active, the cross CAF of scattered pilots of different OFDM symbols would appear with some peaks in some special lags. The baseband of CMMB signals can be written as

$$S(t) = \sum_{n=-\infty}^{\infty} \sum_{i=0}^{N_u-1} Z(i,n) e^{j2\pi \frac{i}{T_u} t} p(t-nT_s) \tag{5}$$

where n is the nth OFDM symbol and i is the ith subcarrier. $Z(i,n)$ is the effective subcarriers N_v mapped to the used subcarriers N_u , i.e. N_u=1024 when B=2MHz. The total subcarriers $N_s = N_u + N_{cp}$, of which N_{cp} is the number of cyclic prefixes. T_u is the used time of an OFDM symbol, and $T_s = T_u + T_{cp}$ is the total time of an OFDM symbol. T_{cp} is the duration of cyclic prefix, and $p(t-nT_s)$ is a rectangular pulse function.

The positions of scattered pilots are different for the odd and even OFDM symbols. Here, to determine the cyclostationary feature, the odd and even baseband OFDM symbols of CMMB can be written in the form of the summation of data subcarriers and scattered pilot subcarriers defined as (6) and (7), respectively. In (6) and (7), $d(i,n)$ is the data information. $a(I_{o1}(l),n)$ and $a(I_{o2}(l),n)$ are the scattered pilot subcarriers in the odd OFDM symbols. $a(I_{e1}(l),n)$ and $a(I_{e2}(l),n)$ are the scattered pilot subcarriers in the even OFDM symbols. $N_p = 39$ is half the pilot subcarriers of an OFDM symbol, and

$L_p = 8$ is the scattered pilot interval. For the odd OFDM symbols, $I_{o1}(l) = S_{o1} + L_p l, l = 0,1,\cdots,N_p - 1$, is the position of the first half of pilot subcarriers, S_{o1} is the starting pilot subcarrier. $I_{o2}(l) = S_{o2} + L_p l, l = N_p, N_p + 1,\cdots,2N_p - 1$, is the position of the second half of pilot subcarriers, S_{o2} is the starting pilot subcarrier. $I_{e1}(l)$, $I_{e2}(l)$, S_{e1}, and S_{e2} are the same definitions for the even OFDM symbols.

$$S_o(t) = \sum_{\substack{n=-\infty \\ n=odd}}^{\infty} \left(\sum_{\substack{i=0 \\ i \neq I_{o1}(l) \\ i \neq I_{o2}(l)}}^{N_u - 1} d(i,n) e^{j2\pi \frac{i}{T_u} t} + \sum_{l=0}^{N_p - 1} a(I_{o1}(l),n) e^{j2\pi \frac{S_{o1} + L_p l}{T_u} t} + \sum_{l=N_p}^{2N_p - 1} a(I_{o2}(l),n) e^{j2\pi \frac{S_{o2} + L_p l}{T_u} t} \right) \cdot p(t - nT_s) \tag{6}$$

$$S_e(t) = \sum_{\substack{n=-\infty \\ n=even}}^{\infty} \left(\sum_{\substack{i=0 \\ i \neq I_{e1}(l), \\ i \neq I_{e2}(l)}}^{N_u - 1} d(i,n) e^{j2\pi \frac{i}{T_u} t} + \sum_{l=0}^{N_p - 1} a(I_{e1}(l),n) e^{j2\pi \frac{S_{e1} + L_p l}{T_u} t} + \sum_{l=N_p}^{2N_p - 1} a(I_{e2}(l),n) e^{j2\pi \frac{S_{e2} + L_p l}{T_u} t} \right) \cdot p(t - nT_s) \tag{7}$$

C. Scattered Pilot Detection of CMMB Signals based on Data Smoothing

Let $R_{SS}^o(t,\tau)$ denote the autocorrelation function of odd OFDM symbols of the PU of CMMB. It is given by (8).

$$R_{SS}^o(t,\tau) = \sum_{\substack{n=-\infty \\ n=odd}}^{\infty} \left\{ \sum_{\substack{i=0 \\ i \neq I_{o1}(l), \\ i \neq I_{o2}(l)}}^{N_u - 1} E\left[d(i,n) d^*(i,n) \right] e^{j2\pi \frac{i}{T_u} \tau} + \sum_{l=0}^{N_p - 1} E\left[a(I_{o1}(l),n) a^*(I_{o1}(l),n) \right] e^{j2\pi \frac{S_{o1} + L_p l}{T_u} \tau} + \sum_{l=N_p}^{2N_p - 1} E\left[a(I_{o2}(l),n) a^*(I_{o2}(l),n) \right] e^{j2\pi \frac{S_{o2} + L_p l}{T_u} \tau} \right\} \cdot p(t + \frac{\tau}{2} - nT_s) p^*(t - \frac{\tau}{2} - nT_s) \tag{8}$$

$$R_{SS}^o(t,\tau) = \left[\sigma_{u,o}^2 \sum_{i=0}^{N_u - 1} e^{j2\pi \frac{i}{T_u} \tau} - \left(\sigma_{u,o}^2 - \sigma_{p1,o}^2 \right) \sum_{l=0}^{N_p - 1} e^{j2\pi \frac{S_1 + L_p l}{T_u} \tau} - \left(\sigma_{u,o}^2 - \sigma_{p2,o}^2 \right) \sum_{l=N_p}^{2N_p - 1} e^{j2\pi \frac{S_2 + L_p l}{T_u} \tau} \right] \cdot \sum_{n=-\infty}^{\infty} p(t + \frac{\tau}{2} - nT_s) p^*(t - \frac{\tau}{2} - nT_s) \tag{9}$$

Assuming the modulated signal $S(t)$ is independent, and identically distributed (*i.i.d*), then $E\left[d(i,n) d^*(i,n) \right]$ is equal to the average power $\sigma_{u,o}^2$ of odd data subcarriers. $E\left[a(I_{o1}(l),n) a^*(I_{o1}(l),n) \right]$ and $E\left[a(I_{o2}(l),n) a^*(I_{o2}(l),n) \right]$ are equal to the average powers of the first and the second half of scattered pilot subcarriers in the odd OFDM symbols, $\sigma_{p1,o}^2$ and $\sigma_{p2,o}^2$, respectively. Then (8) is simplified to (9).

The sum terms of (9) can be simplified according to Euler's formula. For example,

$$\sum_{i=0}^{N_u - 1} e^{j2\pi \frac{i}{T_u} \tau} = \frac{1 - e^{j2\pi \frac{N_u}{T_u} \tau}}{1 - e^{j2\pi \frac{\tau}{T_u}}} = \frac{e^{j\pi \frac{N_u}{T_u} \tau} (e^{-j\pi \frac{N_u}{T_u} \tau} - e^{j\pi \frac{N_u}{T_u} \tau})}{e^{j\pi \frac{\tau}{T_u}} (e^{-j\pi \frac{\tau}{T_u}} - e^{j\pi \frac{\tau}{T_u}})} = \frac{sin(\frac{N_u \pi \tau}{T_u})}{sin(\frac{\pi \tau}{T_u})} \cdot e^{j\pi (N_u - 1) \frac{\tau}{T_u}} \tag{10}$$

The other two sum terms can be simplified similarly.

Considering the finite representation, the Fourier coefficient of the second term in (9) is denoted by

$$R_{pp}^{\alpha}(\tau) = \frac{1}{T_s} \int_{-\frac{T_s}{2}}^{\frac{T_s}{2}} \sum_{n=-\infty}^{\infty} p(t + \frac{\tau}{2} - nT_s) p^*(t - \frac{\tau}{2} - nT_s) e^{-j2\pi \alpha t} dt = \frac{1}{T_s} \int_{-\frac{T_s}{2}}^{\frac{T_s}{2}} p(t + \frac{\tau}{2}) p^*(t - \frac{\tau}{2}) e^{-j2\pi \alpha t} dt \tag{11}$$

where α is an integer multiple of $1/T_s$. Given that $p(t)$ is a rectangular pulse with a value of 1 for $-T_s \le t \le T_s$ and a value of 0 elsewhere, if $\tau > 0$, we have

$$R_{pp}^{\alpha}(\tau) = \frac{1}{T_s} \int_{\frac{-T_s + \tau}{2}}^{\frac{T_s - \tau}{2}} e^{-j2\pi \alpha t} dt = \frac{sin[\pi \alpha (T_s - \tau)]}{\pi \alpha T_s} \tag{12}$$

Similarly, if $\tau < 0$, $R_{pp}^{\alpha}(\tau)$ is equal to $\frac{sin[\pi \alpha (T_s + \tau)]}{\pi \alpha T_s}$.

Considering the above two cases, $R_{pp}^{\alpha}(\tau)$ becomes

$$R_{pp}^{\alpha}(\tau) = \frac{sin[\pi \alpha (T_s - |\tau|)]}{\pi \alpha T_s} \tag{13}$$

By substitution in the finite representation of (3) and (4), and considering (10) and (13), the CAF, $R_{SS}^{o,\alpha}(\tau)$ of $R_{SS}^o(t,\tau)$ is given by (14).

$$R_{SS}^{o,\alpha}(\tau)=\left\{\sigma_{u,o}^{2}\frac{sin(\frac{N_u\pi\tau}{T_u})}{sin(\frac{\pi\tau}{T_u})}\cdot e^{j\pi(N_u-1)\frac{\tau}{T_u}}-\frac{sin(\frac{N_pL_p\pi\tau}{T_u})}{sin(\frac{L_p\pi\tau}{T_u})}\cdot\left[\left(\sigma_{u,o}^2-\sigma_{p1,o}^2\right)e^{j\pi[2S_{o1}+L_p(N_p-1)]\frac{\tau}{T_u}}+\left(\sigma_{u,o}^2-\sigma_{p2,o}^2\right)e^{j\pi[2S_{o2}+L_p(3N_p-1)]\frac{\tau}{T_u}}\right]\right\}\cdot\frac{sin[\pi\alpha(T_s-|\tau|)]}{\pi\alpha T_s} \tag{14}$$

Similarly, the CAF, $R_{SS}^{e,\alpha}(\tau)$ of even OFDM symbols can be written as (15).

$$R_{SS}^{e,\alpha}(\tau)=\left\{\sigma_{u,e}^{2}\frac{sin(\frac{N_u\pi\tau}{T_u})}{sin(\frac{\pi\tau}{T_u})}\cdot e^{j\pi(N_u-1)\frac{\tau}{T_u}}-\frac{sin(\frac{N_pL_p\pi\tau}{T_u})}{sin(\frac{L_p\pi\tau}{T_u})}\cdot\left[\left(\sigma_{u,e}^2-\sigma_{p1,e}^2\right)e^{j\pi[2S_{e1}+L_p(N_p-1)]\frac{\tau}{T_u}}+\left(\sigma_{u,e}^2-\sigma_{p2,e}^2\right)e^{j\pi[2S_{e2}+L_p(3N_p-1)]\frac{\tau}{T_u}}\right]\right\}\cdot\frac{sin[\pi\alpha(T_s-|\tau|)]}{\pi\alpha T_s} \tag{15}$$

Equation (14) and (15) show the CAFs of the PU of CMMB with the scattered pilot structure where α is an integer multiple of $1/T_s$, and the values of CAFs are influenced dominantly by the scattered pilots. It can be observed that $R_{SS}^{o,\alpha}(\tau)$ and $R_{SS}^{e,\alpha}(\tau)$ generate peaks for $\alpha=0$ and approximately $\tau=n T_u/L_p, n=1,2,\cdots,7$. Indeed, the starting subcarrier of scattered pilots is also different for every two adjacent symbols. Therefore, only two symbols of CMMB generate some well-detectable peaks at approximately $\tau=2n T_u/L_p = n T_u/4, n=1,2,3$.

According to the CAF of odd OFDM symbols, we can make the decision on whether the PU of CMMB is active or not.

$$\begin{cases} H_1: & R_{SS}^{o,\alpha}(\tau)\ge\lambda_o \\ H_0: & R_{SS}^{o,\alpha}(\tau)<\lambda_o \end{cases} \tag{16}$$

We can also make decision according to the CAF of even OFDM symbols.

$$\begin{cases} H_1: & R_{SS}^{e,\alpha}(\tau)\ge\lambda_e \\ H_0: & R_{SS}^{e,\alpha}(\tau)<\lambda_e \end{cases} \tag{17}$$

where λ_o and λ_e, respectively, are the decision thresholds of the decision statistics for the odd and even OFDM symbols. For a target probability of false alarm, λ_o and λ_e are obtained by Monte Carlo simulation only if the noise exists.

In order to improve the detection probability of CMMB signals, we use the OR rule to make the final decision in this paper.

$$\begin{cases} H_1: & R_{SS}^{o,\alpha}(\tau)\ge\lambda_o \ or \ R_{SS}^{e,\alpha}(\tau)\ge\lambda_e \\ H_0: & R_{SS}^{o,\alpha}(\tau)<\lambda_o \ and \ R_{SS}^{e,\alpha}(\tau)<\lambda_e \end{cases} \tag{18}$$

As shown in (14) and (15), the average powers of data subcarriers and scattered pilot subcarriers have a great influence on the decision statistics. Taking into account circularly symmetric complex Gaussian (CSCG) noises and the advantage of the first order lag filter, we use the first order lag filter to smooth the received data. Assuming the smoothed data of the *n*th OFDM symbol and *i*th subcarrier is $\overline{S}(i,n)$, we have

$$\overline{S}(i,n)=(1-b)\cdot S(i,n)+b\cdot\overline{S}(i-1,n),\ b\in(0,1) \tag{19}$$

where $S(i,n)$ is the received signal interfered with the noise, $\overline{S}(i-1,n)$ is the last smoothed data, and b is the smoothing factor. Hence, the decision rule is denoted by

$$\begin{cases} H_1: & \overline{R}_{SS}^{o,\alpha}(\tau)\ge\overline{\lambda}_o \ or \ \overline{R}_{SS}^{e,\alpha}(\tau)\ge\overline{\lambda}_e \\ H_0: & \overline{R}_{SS}^{o,\alpha}(\tau)<\overline{\lambda}_o \ and \ \overline{R}_{SS}^{e,\alpha}(\tau)<\overline{\lambda}_e \end{cases} \tag{20}$$

where $\overline{R}_{SS}^{o,\alpha}(\tau)$ and $\overline{R}_{SS}^{e,\alpha}(\tau)$ are the new decision statistics computed with the smoothed data in (14) and (15). $\overline{\lambda}_o$ and $\overline{\lambda}_e$ are correspondingly the new decision thresholds.

D. Complexity

The complexity of the proposed algorithm in case of the number of multiplications can be expressed in terms of $O(MN_s)$, where M is the number of OFDM symbols used for the spectrum sensing. The proposed algorithm has a lower complexity than the second-order cyclic cumulants form using multiple cycle frequencies with the same one delay lag, which is denoted by $O\left(M\cdot(L N_s^2+N_s logN_s)\right)$, where L is the odd length of a spectral window. Even considering one cyclic frequency, the form of second-order cyclic cumulants still has a higher complexity with $O\left(M\cdot(LN_s+N_s)\right)$.

IV. Numerical and Simulation Results

This section provides analytical and simulation results to verify the theoretical deduction above and compares the detection performance under different SNRs. It is assumed that the bandwidth is 2MHz, and the subcarrier modulation is QAM16. The special delay lag τ is set to $T_u/4$. Obviously, the bigger the value of the smoothing factor *b*, the better the smoothing effect is for $\overline{S}(i,n)$. Hence, the smoothing factor *b*=0.99 is set for all simulations. The channel is assumed to be AWGN.

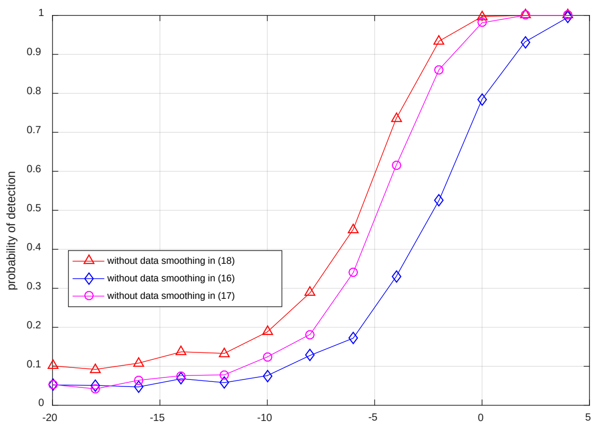

Fig. 2. Probabilities of detection of different schemes without data smoothing

Fig. 2 compares the probabilities of detection under the detection schemes based on (16), (17), and the OR rule combination in (18). The number of OFDM symbols used for spectrum sensing is M=108, which is equal to two slot times (50ms) of a CMMB frame. It can be verified that the CAF of the odd or even OFDM symbols of CMMB signals has the peak value in a special delay lag, and this can be used to sense the PU of CMMB. The detection performance of the OR rule combination method is better than that of the other two schemes because of the advantage of the OR rule. However, the detection capabilities degrade rapidly in lower SNR, e.g. SNR<-2dB.

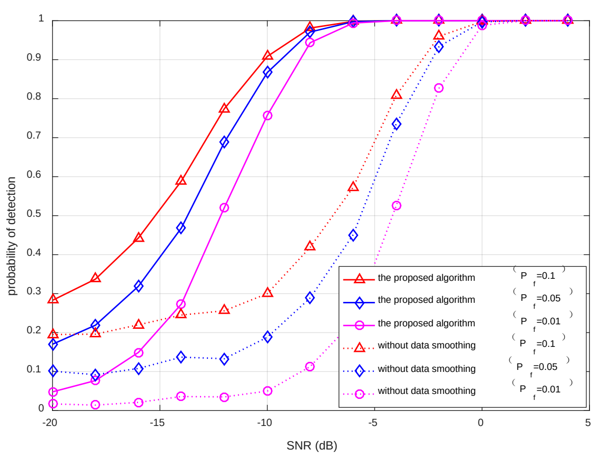

Fig. 3. Probabilities of detection of the proposed algorithm

Compared with the sensing method based on (18) without data smoothing, we then show the detection performance of the proposed algorithm in which the received data has been smoothed by the first order lag filter. Fig. 3 thus illustrates the probabilities of detection under different probabilities of false alarm. The sensing time is 50ms (M=108). It is obviously observed that the detection probability increase as the false alarm probability increases. The proposed algorithm outperforms the detection scheme without data smoothing in all cases. For example, the probability of detection of the proposed algorithm is 60% higher than that of the method without data smoothing for P_f=0.1 , SNR= -10dB. For the proposed algorithm, it is easy to accurately decide whether the PU of CMMB is present or not in these low SNR environments.

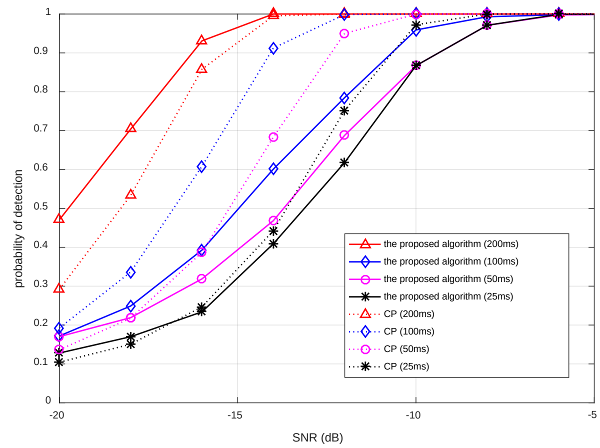

Fig. 4. Probabilities of detection of the proposed algorithm and CP method

Fig. 4 shows the results of the proposed algorithm and the CP method in [8]. The target probability of false alarm, P_f , is 0.05. The sensing time of 25ms, 50ms, 100ms, and 200ms are used, which are equal to the number of OFDM symbols M=54, 108, 216, and 432, respectively. It can be observed that the detection probability of the proposed method improves significantly as the sensing time increasing. The reason originates from more scattered pilots with a long detection time. Therefore, the cyclostationarity of scattered pilots is more obvious. For instance, the improvement of detection capability with a sensing time of 200ms is about 5dB compared with that of sensing time of 100ms. If there is a short sensing time (e.g. 25ms, 50ms, or 100ms), the CP method outperforms the proposed algorithm. However, the proposed method exhibits a better detection performance with a longer detection time. As shown in Fig. 4, the proposed algorithm has a better detection capability than the CP method for sensing time of 200ms. The performance improvement is about 1-2dB for lower SNR, e.g. SNR< -17dB. Furthermore, the complexity of the CP method in case of the number of multiplications, $O(N_{cp}\cdot(MN_s))$ is times the proposed scheme.

V. CONCLUSION

A scattered pilot detection of CMMB signals based on data smoothing for CRNs is proposed. The CAF values of the smoothed signals positioned in the special delay lags is computed directly to detect the PU of CMMB, and the decision statistics is derived. The proposed algorithm has a lower complexity than the multiple cycle frequencies detection schemes of second-order or higher order cyclic cumulants form. The results of simulation indicate that the detection performance is significantly improved with longer sensing time.

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