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A Novel Cognitive Frequency Hopping Detection Algorithm

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Abstract. Cognitive frequency hopping technology is to apply cognitive radio to frequency hopping communication. The spectrum hole in cognitive frequency hopping spectrum can be detected effectively to avoid the collision of frequency points and improve the spectral efficiency to update the frequency hopping points. The time domain correlation algorithm in spectrum detection technology for cognitive radio has some defects in anti-interference, universality and real time performance due to the existence of noise and primary signals. A time domain correlation algorithm based on power spectrum cancellation is proposed to detect the cognitive frequency hopping spectrum. The proposed algorithm can be used to improve the detection probability of signals. Moreover, it can overcome the noise uncertainty and restrain the primary signals. Theoretical analysis and computer simulation demonstrate that the time domain correlation algorithm based on power spectrum cancellation is superior to traditional time domain correlation algorithm.

Keywords: Cognitive Frequency Hopping, Time-Domain Correlation, Power Spectrum Cancellation, Spectrum Hole.

1. Introduction

Duu to the low interception rate and anti-interference, frequency hopping communication is extensively applied to military communication and electronic warfare. At present, most tactical communication radios adopt frequency hopping technology to improve the anti-interference ability of communication and to overcome the near-far effect in communication. With the deepening of relevant studies about cognitive radio technology, it has become a research hotspot to increase the performance of frequency hopping communication by utilizing cognitive radio technology.

Cognitive frequency hopping (CHF) technology applies CR technology to frequency hopping communication (FH). See Fig.1 for the structure diagram of cognitive frequency hopping system.

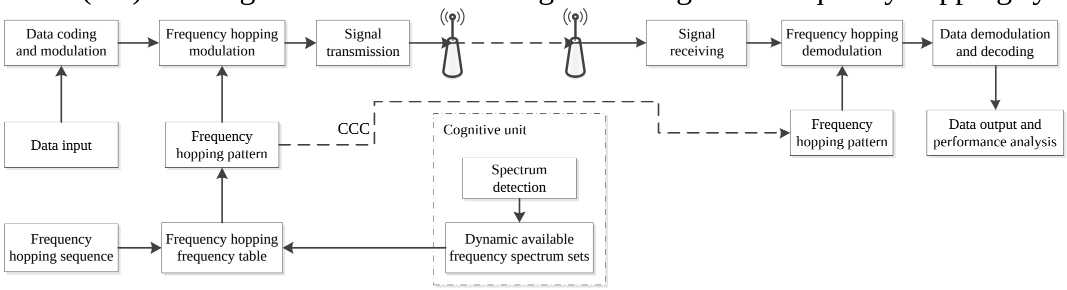


Fig. 1 Structure diagram of cognitive frequency hopping system

Cognitive frequency hopping system is involved in this paper. Owing to the uncertainty of frequency point locations, filter matching and delay multiplication detection methods are not applicable. Meanwhile, power spectrum of frequency hopping signal changes with time, so it is very difficult to use energy detection and circle detection methods. In this paper, a cognitive frequency hopping spectrum detection algorithm based on power spectrum cancellation in time-domain correlation (hereinafter referred to as PCTC algorithm) is proposed. To realize totally blind spectrum detection in the cognitive frequency hopping system, it can overcome noise uncertainty, restrain interference of authorized signals, and improve detection probability.

2. Cognitive Frequency Hopping System Model

The signal $x(t)$ model received by SU in cognitive frequency hopping system is as follows:

$$x(t)=\begin{cases} n(t) & H_0 \\ S_H(t)+n(t) & H_1 \\ S_H(t)+S_F(t)+n(t) & H_2 \end{cases} \tag{1}$$

H_0 means that the received signal contains noise $n(t)$ only; H_1 means that the received signal contains frequency hopping signal $S_H(t)$ and noise $n(t)$; H_2 means that the received signal contains. $n(t)$ and PU signal $S_F(t)$. The noise belongs to additive white Gaussian noise (AWGN).

Autocorrelation function $R_x(\tau)$ of the received signal is obtained.

$$R_x(\tau)=E[x(t)x(t+\tau)]=\begin{cases} R_{SS_{NN}}(\tau) & H_0 \\ R_{SS_{HH}}(\tau)+R_{NN}(\tau)+R_{S_HN}(\tau) & H_1 \\ R_{SS_{HH}}(\tau)+R_{SS_{FF}}(\tau)+R_{NN}(\tau)+... & \\ R_{S_HS_F}(\tau)+R_{S_FS_H}(\tau)+R_{S_HN}(\tau)+... & H_2 \\ R_{NS_H}(\tau)+R_{S_FN}(\tau)+R_{NS_F}(\tau) & \end{cases} \tag{2}$$

$R_{SS_{HH}}(\tau)$ refers to autocorrelation of frequency hopping signals; $R_{NN}(\tau)$ means autocorrelation of noises; $R_{S_HN}(\tau)$ indicates cross-correlation of frequency hopping signals and noises; $R_{SS_{FF}}(\tau)$ signifies autocorrelation of PU signals; $R_{S_HS_F}(\tau)$ and $R_{S_HS_F}(\tau)$ denote cross-correlation of frequency hopping signals and PU signals. Noise and frequency hopping signal have a very small correlation with cognitive signal, which can be ignored. $n(t)$ is the random function which has no correlation; $S_F(t)$ and $S_H(t)$ are two different signals which do not have a correlation either. Therefore, $R_x(\tau)$ is related to autocorrelation of $S_H(t)$ and $S_F(t)$ only.

3. Steps of PCTC Algorithm

Fig. 2 shows the flow chart of PCTC algorithm.

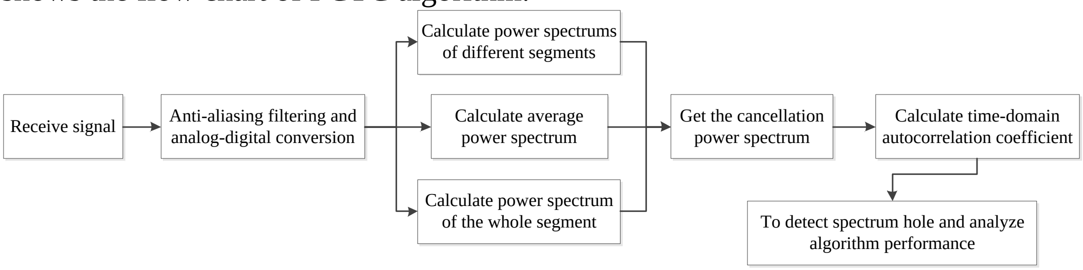


Fig. 2 Flow chart of PCTC algorithm

Convert the signal $x(t)$ received into digital sequence $x(n)$ through anti-aliasing filter and analog-digital converter. Divide $x(n)$ into T continuous data segments. The length of every data segment is M. Suppose that the received signal meets hypothesis H_2, and signal of segment t can be expressed. Conduct FFT operation for $x_t(n)$ to solve the power spectrum of $x_t(n)$. Obtain the average power for the power spectrum of every data segment.

$$\begin{gathered} x_t(n)=\sum_{i=1}^{a}S_{Fi}(n)+\sum_{j=1}^{b}S_{Hj}(n)+n(n) \\ S_{all}(k)=\frac{1}{N}\left|X_t(k)\right|^2=\frac{1}{N}\left|\sum_{k=1}^{N}x_t(n)e^{-jwk}\right|^2 \\ S_{avg}(k)=\overline{S}_t(k)=\frac{1}{LM}\sum_{l=1}^{L}\left|\sum_{k=1}^{M}x_l(n)e^{-jwk}\right|^2 \end{gathered} \tag{3}$$

Owing to the existence of PU, the characteristic ratio has an obvious increment no matter whether it is in T_H. $R_x'(\tau)$ after power spectrum cancellation is used to replace $R_x(\tau)$.

$$\rho' = \frac{E_1}{E_2} = \frac{(T-T_H)\int_0^{T_H}(R_x'(\tau))d\tau}{T_H\int_{T_H}^{T}(R_x'(\tau))d\tau} \tag{4}$$

For hypothesis H_0 , ρ' is ρ_0 . For hypothesis H_1 , ρ' is ρ_1 . For hypothesis H_2 , ρ' is ρ_2 .

$$\begin{aligned}
\rho_0 &= \rho \mid H_0 = \frac{(T-T_H)\int_0^{T_H}(R_{SS_{NN}}(\tau))d\tau}{T_H\int_{T_H}^{T}(R_{SS_{NN}}(\tau))d\tau} \\
\rho_1 &= \rho \mid H_1 \cong \frac{(T-T_H)\int_0^{T_H}\left|R_{SS_{HH}}(\tau)+R_{SS_{NN}}(\tau)\right|d\tau}{T_H\int_{T_H}^{T}R_{SS_{NN}}(\tau)d\tau} \\
\rho_2 &= \rho \mid H_2 \cong \frac{(T-T_H)\int_0^{T_H}\left|R_{SS_{HH}}(\tau)+R_{SS_{FF}}(\tau)+R_{SS_{NN}}(\tau)+R_{S_HS_F}(\tau)+R_{S_FS_H}(\tau)\right|d\tau}{T_H\int_{T_H}^{T}\left|R_{SS_{FF}}(\tau)+R_{SS_{NN}}(\tau)+R_{S_HS_F}(\tau)+R_{S_FS_H}(\tau)\right|d\tau}
\end{aligned} \tag{5}$$

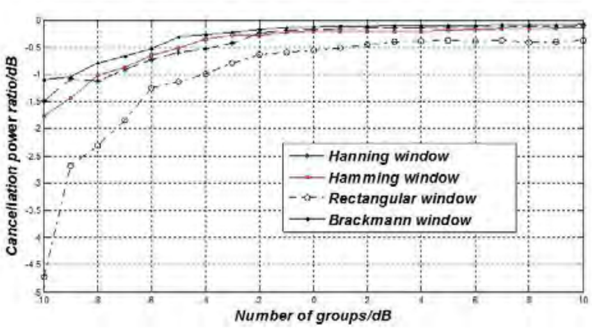
Compare frequency spectrum after power spectrum cancellation with frequency spectrum of $x(t)$. Occupancy of authorized signal for a certain frequency point is judged via short time Fourier transform (STFT) through the spectral line intensity in the specific frequency point location (brightness in the time-frequency image). Hypotheses H_1 and H_2 can be differentiated.

4. Analysis on PCTC Algorithm Performance

4.1 Power Cancellation Performance.

The performance of PCTC algorithm is mainly decided by the cancellation ratio of power spectrum. Cancellation ratio is related to number of data segments, types of window function used by data truncation, and signal-to-noise ratio of received signal. Cancellation ratio of power spectrum is defined as $\frac{S_{SUB}(k)}{S_{all}(k)}(dB)$. The smaller the cancellation ratio is, the better the suppression of cancellation operation on the interference will be. Accordingly, PU signal is weakened more obviously and the detection performance of PCTC algorithm is better.

The number of data segments is determined as 10. As for window function, Hanning window, Hamming window, rectangular window and Brackmann window are selected. Monte-Carlo calculation is conducted for 1,000 times. Fig. 3 shows the relation between signal-to-noise ratio and cancellation ratio of power spectrum. According to the figure, the greater the signal-to-noise ratio is, the better the effect of cancellation operation will be. The signal-to-noise ratio is determined as 5 dB. As for window function, Hanning window, Hamming window, rectangular window and Brackmann window are selected. Monte-Carlo calculation is conducted for 1,000 times. Fig. 4 shows the relation between number of groups and cancellation ratio of power spectrum. According to the figure, when Hanning window, Hamming window and Brackmann window are chosen, the number of groups does not have a huge influence on the performance of cancellation operation. However, when rectangular window is selected, the higher the number of groups is, the better the performance of cancellation operation will be. As for the reason, when rectangular window is used to truncate data, frequency spectrum energy loss is obvious. However, all the other three windows will restrain sidelobe energy to some extent.



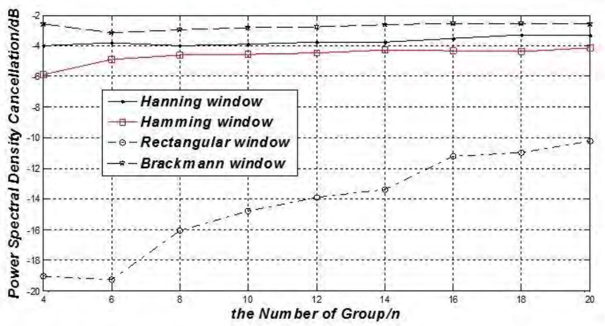


Fig. 3 the influence of window function on cancellation operation Fig. 4 the influence of number of groups on cancellation operation

4.2 Detection Probability Performance.

A comparison is made between PCTC algorithm and traditional time-domain correlation algorithm when the number of segments is high (10), Brackmann window is selected as the window function, and signal-to-noise ratio is set as 5 dB. Fig. 15 shows the comparison of detection probability between time-domain correlation algorithm based on power spectrum cancellation and traditional time-domain correlation algorithm when the false alarm probability P_f (false alarm probability means the probability of mistakenly detecting the spectrum hole as the state that frequency spectrum is occupied) is 0.05, the detection threshold is substituted into formula (16), the total number of data points generated via DDS method is 20,000, and the modulation mode is BPSK in cognitive frequency hopping system. According to Fig. 5, under low signal-to-noise ratio of detection, time-domain correlation algorithm based on power spectrum cancellation is superior to traditional time-domain correlation algorithm, and the detection probability is increased obviously.

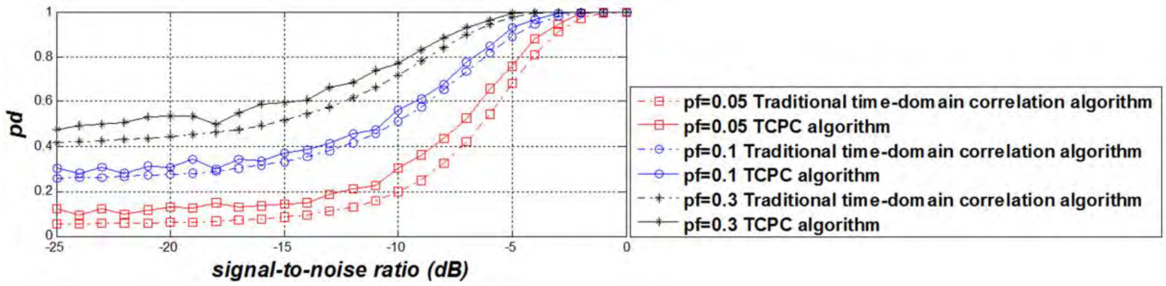


Fig. 5 The comparison between time-domain correlation algorithms

5. Summary

Cognitive frequency hopping system is superior to traditional frequency hopping system in many aspects. However, whether spectrum hole exists in the frequency point pattern should be determined at first. After introducing the existing spectrum detection methods, this paper puts forward a time-domain correlation algorithm based on power spectrum cancellation, to detect spectrum hole in cognitive frequency hopping system. Theoretical derivation, simulation realization and performance analysis of this algorithm are explained. Finally, this algorithm proves to obviously improve the detection probability for spectrum hole, and its performance is better than that of traditional time-domain correlation algorithm. Time-domain correlation algorithm based on power spectrum cancellation can realize totally blind spectrum detection, providing a solution for spectrum detection of cognitive frequency hopping system.

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